The Journal of the American Association of Zoo Keepers, Inc.

AKF

# Animal Keepers' Forum

## Best Practices in Lighting

Presented by the American Association of Zoo Keepers and The Zoological Lighting Institute

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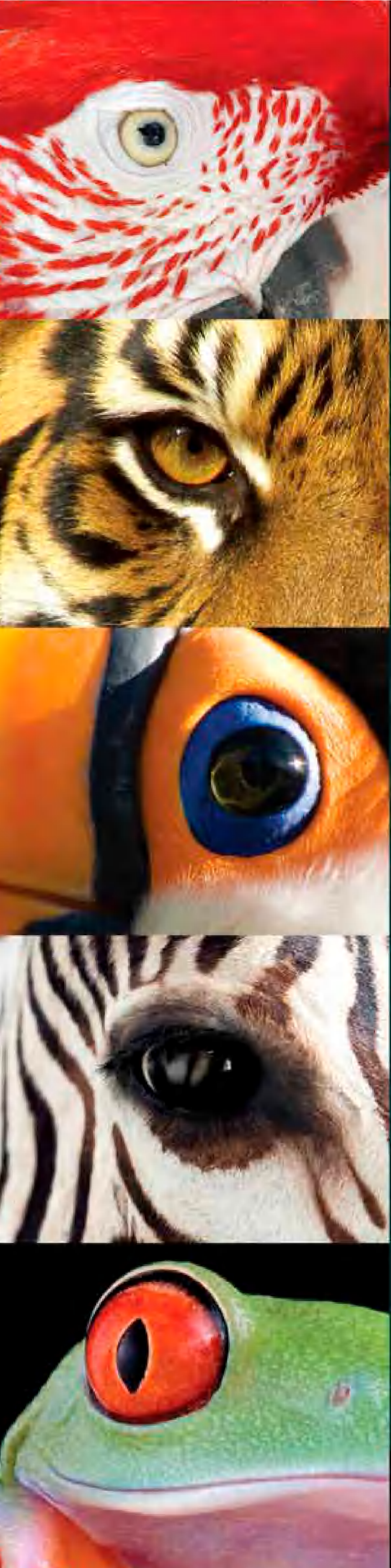



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## MISSION STATEMENT

American Association of Zoo Keepers, Inc.

The American Association of Zoo Keepers, Inc. exists to advance excellence in the animal keeping profession, foster effective communication beneficial to animal care, support deserving conservation projects, and promote the preservation of our natural resources and animal life.

## About the Cover

This month's cover photo comes to us from Ashley Arimborgo of Cheyenne Mountain Zoo. “Amaro" is a Golden Lion Tamarin (*Leontopithecus rosalia*) and resides at Cheyenne Mountain Zoo with his mom Graciela, and his twin brother Bernardo. Males will help raise the offspring and will often carry the young (typically twins) on their backs in-between feedings. The family groups reside primarily in trees and sleep in hollows at night. As omnivores, they enjoy a variety of fruit, lizards, insects, and even birds (in captivity their primary diet is mealworms and a fruit mix, along with canned marmoset diet).

GLTs are critically endangered, as are the rainforests in Brazil where they are found. Logging, agriculture, and industry are the main reasons for the deforestation that is occurring. There are conservation projects working to preserve their habitat and to educate the local people about their importance. Go to P. 33 to learn more about how Cheyenne Mountain Zoo is providing ultraviolet lighting for their GLTs and other Callitrichidae, and the observed impacts this lighting has on animal welfare.

Articles sent to ***Animal Keepers' Forum*** will be reviewed by the editorial staff for publication. Articles of a research or technical nature will be submitted to one or more of the zoo professionals who serve as referees for ***AKF***. No commitment is made to the author, but an effort will be made to publish articles as soon as possible. Lengthy articles may be separated into monthly installments at the discretion of the Editor. The Editor reserves the right to edit material without consultation unless approval is requested in writing by the author. Materials submitted will not be returned unless accompanied by a stamped, self-addressed, appropriately-sized envelope. Telephone, fax or e-mail contributions of late-breaking news or last-minute insertions are accepted as space allows. Phone (330) 483-1104; FAX (330) 483-1444; e-mail is shane.good@aazk.org. If you have questions about submission guidelines, please contact the Editor. Submission guidelines are also found at: aazk.org/akf-submission-guidelines/.

Deadline for each regular issue is the 3rd of the preceding month. Dedicated issues may have separate deadline dates and will be noted by the Editor.

Articles printed do not necessarily reflect the opinions of the ***AKF*** staff or the American Association of Zoo Keepers, Inc. Publication does not indicate endorsement by the Association.



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## *ANIMAL KEEPERS' FORUM*

**TO CONTACT THE *AKF* EDITOR:**
Shane Good, AKF Editor
P.O. Box 535, Valley City, OH 44280
330-483-1104
Shane.Good@aazk.org

## AAZK Administrative Office

American Association of Zoo Keepers
8476 E. Speedway Blvd. Suite 204
Tucson, AZ 85710-1728
520-298-9688 (Phone/Fax)
**CHIEF EXECUTIVE/FINANCIAL OFFICER:** Ed Hansen
E-mail: Ed.Hansen@aazk.org

***ANIMAL KEEPERS' FORUM* - EDITOR**
Shane Good, Shane.Good@aazk.org
**GRAPHIC DESIGNER**
Elizabeth Thibodeaux, Elizabeth.Thibodeaux@aazk.org
**ENRICHMENT OPTIONS COLUMN COORDINATORS**
Julie Hartell-DeNardo, Heather Dunn
Dawn Neptune
**TRAINING TALES COLUMN COORDINATORS**
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# THANK YOU

to **The Zoological Lighting Institute** for sponsoring this dedicated issue of the *AKF!*

The American Association of Zoo Keepers (AAZK) exists to advance excellence in the animal keeping profession. This issue of the *Animal Keepers' Forum* dedicated to Best Practices in Lighting for Zoo and Aquarium Animals is a testament to the members of AAZK who continue to advance our profession, even in some of the ways that don't always get covered in press releases or annual reports. Conservation success stories and cute baby animals deservedly get the headlines, but the hard work that goes into getting difficult-to-reproduce species to breed often involves animal care professionals perfecting sometimes unmentioned techniques like lighting.

As Dr. James Karl Fischer of The Zoological Lighting Institute points out in his article beginning on P. 12, lighting for zoo animals is complex, particularly because we are all familiar with it. It is easy to assume through old assumptions and some quick glances at the cover of a light bulb box that we are providing what our animals need. But delve into the deeper topics of lighting and it becomes easy to see that most of us need to do a little more research when wanting to provide the best in lighting for our animals: Spectral Power Distribution Curves, bulb decay, lighting options for nocturnal animals, photoperiods, Ferguson Zones, light therapy for animals, lighting in mixed-species exhibits, the behavioral and hormonal impacts of lighting on animals, not to mention the multitude of lighting options available on the market today. These topics shed just a few examples of some of the complexities of providing lighting to animals.

I want to personally thank Dr. James Karl Fischer, Executive Director of The Zoological Lighting Institute, and Linda Henry, Supervisor of Penguin Encounter, SeaWorld San Diego, for their assistance in creating this special dedicated issue of the *Animal Keepers' Forum*. Our shared vision was to open a dialogue with zoo professionals toward improving lighting that continues beyond this edition of the AKF. I also want to thank the authors who contributed to this issue of the AKF. If there is a theme of this issue, it would be that lighting is critically important to the health, behavior and reproduction of our zoo and aquarium animals. These authors did a tremendous job toward supporting the AAZK mission of advancing professional animal care.

**Did this issue of the AKF create questions that you have about any topic related to the Best Practices in Lighting for Animals in Zoos and Aquariums? Send your questions to me at shane.good@aazk.org and our panel of lighting experts will answer your questions in an upcoming issue of the AKF.**

Best Regards,

Shane Good
AKF Editor

# COMING EVENTS

**Post upcoming events here!**
**e-mail shane.good@aazk.org**

**March 11-15, 2017**
**23rd Annual Aquatic Animal Life Support Operators (ALLOYS) Symposium**
St. Louis, MO
Hosted by Saint Louis Zoo
For more information go to:
www.aalso.org

**March 26-31, 2017**
**AZA Mid-Year Meeting**
Albuquerque, NM
Hosted by ABQ BioPark
For more information go to:
aza.org/conferences-meetings

**April 17-20, 2017**
**African Painted Dog Conference**
Topeka, KS
Hosted by Topeka Zoo
For more information go to:
http://topekazoo.org/APDconference/

**April 17-22, 2017**
**AZA Best Practices in Animal Keeping Course**
Buffalo, NY
Hosted by Buffalo Zoo
For more information go to:
aza.org

**April 23-28, 2017**
**ABMA Annual Conference**
Cincinnati, OH
Hosted by Cincinnati Zoo and Botanical Garden.
For more information go to:
theabma.org/abma-annual-conference/

**June 5-9, 2017**
**Practical Zoo Nutrition Management**
Front Royal, VA
Hosted by the Smithsonian-Mason School of Conservation and the National Zoological Park
For more information go to:
http://smconservation.gmu.edu/programs/graduate-and-professional/professional-training-courses/nutrition/

**July 12-22, 2017**
**International Herpetological Symposium**
Rodeo, NM
Hosted by Chiricahua Desert Museum
For more information go to:
internationalherpetologicalsymposium.com/40th-annual-symposium/

**July 31 - Aug 4, 2017**
**Elephants 360: Advancing Health and Wellness**
Cleveland, OH
Hosted by Cleveland Metroparks Zoo
Registration info coming soon!

**August 28-30, 2017**
**Old World Monkey Husbandry Workshop**
Columbus, OH
Hosted by Columbus Zoo
For more information contact Audra Meinelt:
Audra.Meinelt@columbuszoo.org

AMERICAN ASSOCIATION of ZOO KEEPERS

**August 27-31, 2017**
**AAZK National Conference**
**Washington, D.C.**

***Hosted by the National Capital AAZK Chapter and Smithsonian's National Zoo***

**facebook.com/AAZK2017**

**September 9-13, 2017**
**AZA Annual Conference**
Indianapolis, IN
Hosted by Indianapolis Zoo
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# CALL FOR NOMINATIONS
# AAZK Board of Directors

The American Association of Zoo Keepers (AAZK) is seeking nominations for four (4) positions on the AAZK Board of Directors. Each candidate shall be nominated by a Professional peer within AAZK. Qualified candidates shall be active Professional Members in good standing with AAZK. AAZK Bylaws require that a Board Member have the title of Animal (Zoo) Keeper or similar and if in a supervisory role at their facility, maintain daily husbandry contact with the animal collection. AAZK reserves the right to contact the candidate's employer to verify candidate's job duties conform to AAZK policy. The electronic voting period to elect Board Members to the Association will be open from **May 1, 2017 to June 1, 2017** on the AAZK website.

**Preferred Experience:**
Experience as an officer in an AAZK Chapter, Committee Chair, or Conference Chair. Excellent organizational and time management skills, coupled with the ability to meet tight deadlines; problem solving and motivation of subordinates and quality public speaking skills.

**Requirements:**
Each elected candidate shall be required to attend monthly electronic meetings of the AAZK Board of Directors, read and answer daily electronic communications, supervise the work of Committees and/or Program Managers and shall be required to attend the annual AAZK Conference. An elected candidate can expect to commit anywhere from 2-4 hours per week in the performance of AAZK Board duties.

**Nominations:**
A Letter of Nomination shall include:

- Name of Candidate
- Zoo Affiliation
- Zoo Position Title
- Contact Information (address) including a phone number
- E-mail address

The Letter of Nomination shall include a brief synopsis of candidate work history, previous experience within AAZK and detail the number of years within the Profession. Deadline for Nominations to the AAZK Board of Directors shall be postmarked or e-mailed prior to midnight **February 28, 2017**.

Nominations can be sent to Ed.Hansen@aazk.org or mailed to:

Ed Hansen, CEO/CFO AAZK
8476 E. Speedway Suite 204
Tucson, AZ 85710-1728

## Reminder – AAZK Professional Members
## AAZK Board of Directors Electronic Voting

Candidate profiles for election to the AAZK Board of Directors may be viewed at www.aazk.org beginning **April 1, 2017.**

Professional Member electronic voting for candidates to the AAZK Board of Directors will open on the AAZK website (www.aazk.org) on **April 15, 2017** and will close at midnight June 1, 2017.

# NEW GRANT BEING OFFERED!

AAZK is now offering a grant specifically for the National Conference. This is a great way to get funding to attend the next conference without competing against other professional development opportunities. If you are interested in applying for the new AAZK National Conference Grant details will soon be on the AAZK website.

> **Qualifications:** Full-time keepers/aquarists in zoological parks and aquariums, who are professional members of AAZK, INC. in good standing, are eligible to receive grants.

AAZK will still be offering the AAZK Professional Development Grant, the Research Grant and the Conservation, Preservation, Restoration Grant. All four grants will be due March 1, 2017 so start thinking now of all the exciting things you can accomplish with these grants.

# 2017 AAZK AWARDS NOMINATIONS OPENED

The American Association of Zoo Keepers' AAZK Awards Committee is accepting nominations for the following awards:

- Lifetime Achievement Award
- Meritorious Service Award
- Lutz Ruhe Meritorious Achievement — AAZK Professional of the Year Award
- Jean M. Hromadka AAZK Excellence in Animal Care Award
- Nico van Strien Leadership in Conservation Award
- Lee Houts Advancement in Enrichment Award
- Certificate of Merit for Zoo Keeper Education
- Certificate of Excellence in Exhibit Renovation
- Animal Nutrition Award

Awards will be presented at the 2017 AAZK Conference in Washington, D.C. The deadline for nominations is 1 May 2017. Information concerning the qualifications, nomination procedure, selection procedure and an explanation of the awards may be obtained at www.aazk.org, under committees/awards.

# Introduction to Lighting for Animal Care 101:

## Conversation with AAZK to produce industry standard reference

James Karl Fischer, Ph.D.
Executive Director
The Zoological Lighting Institute

**ZLI Mission Statement and Description:**

The Zoological Lighting Institute supports photobiology and photo-ecology research to advance animal welfare and wildlife conservation

*The first step in improving animal husbandry techniques as they pertain to lighting, is to recognize that light must be measured regularly as a physical phenomena, in terms of precisely defined physical qualities.*

The Zoological Lighting Institute™ believes that science, particularly in animal related fields, leads to better decision making. We care for animals and the environments necessary to the well-being of all. To improve the practical care for animals, and to protect the environment in meaningful ways, it is necessary to turn to the sciences.

Our mission is to connect animal care and wildlife conservation to photobiology, the study relating light and light qualities to living beings. Doing so will enable the people that care for animals to do so more effectively, whilst staving off a major factor in habitat degradation: light pollution.

As studies repeatedly demonstrate, light is crucial to animal health and behavior. Animals evolved around the globe in response to very specific albeit dynamic natural lighting conditions. This specificity is important to animals, as it allows them to both express a range of natural behavior and to maintain healthy physical bodies. Determining what qualities are important and why, is a subject for scientific inquiry.

*The first step in improving animal husbandry techniques as they pertain to lighting, is to recognize that light must be measured regularly as a physical phenomena, in terms of precisely defined physical qualities.*

'Light' is a challenging subject, particularly as it is so familiar to everyone. Such familiarity sometimes leads people, ourselves included, to forget that it is a complex physical phenomena very separate from normal or casual visual perception. Yet if we wish to understand the relationships of light to living things, it is necessary to ask what qualities of light impact living things, and in what ways. Photobiology depends both upon physical light and the organic material it interacts with. An animal, like a human person, relates to the energies of light in many observable ways that ought to be considered carefully in care and conservation initiatives.

A good first step is to say that the luminous environment of animals in managed care ought to be similar to those found in the 'natural' environment of an animal. We might also say that a 'natural' environment ought to be as free from harmful alternation as much as possible. For architectural and landscape lighting, this means that one ought to consider the use of artificial lighting and the deceptive additions of glass and light polarizing materials quite carefully. Before considering the 'photo' aspects of photobiology though, it is helpful to outlay some of the possible ways in which life relates to light.

The Zoological Lighting Institute has taken the first steps in establishing the parameters for photobiology research relevant to managed care and wildlife conservation. First, it establishes ***three research milieux***: physiology, sensory ecology and ecological partitioning. Second, while it cannot define global measurements relevant to all scientific studies in photobiology (as these will depend upon particular experiments), to be reproducible, it is essential that ***light measurements rely on physical parameters***, rather than industry standards. Finally, because 'light' will always be subjected to cultural expression, even in its most scientific formulation, it is imperative when creating a clinical picture to ***explore regional interpretation of an animal's photo-ethology*** (how animal behavior relating to light and light cycles have been expressed in anecdote, myth and literature).

This is simpler than it might at first seem.

***Research milieux help give studies purpose.*** Physiological studies enable an animal keeper to coordinate hormone levels with lighting conditions. Sensory ecology research aids enrichment programs, in that lighting conditions can be associated with how an animal sees or is typically seen and so, forages, makes breeding selections or other 'decisions'. Ecological partitioning is crucial to understand too, in terms

of dynamic aspects the 'luminous environment'. When and where would an animal pursue its activities within its naturally lit environment? Answers to these questions and their implications (such as population density and interspecies interactions) are fundamental to understanding the health and well-being of animal life on earth. While there may be additional milieux worth exploring, these three (physiology, sensory ecology and partitioning) form a solid basis for understanding.

***Physical optics matter far more than potentially misleading industry standards.*** The first step in improving the luminous husbandry of managed animals, or in protecting the luminous habitat of animals *in-situ*, is to cut ties with misleading standards which can only lead to unreproducible experimental results. Perhaps because light is a very special subject that crosses perception, scientific inquiry and cultural symbolism, many ways have arisen to describe it. Properly targeted data measurement is crucial. Many common methods of 'reading' light, such as lux, lumens, color temperature or CRI, actually tell a researcher absolutely nothing relevant to photobiology. From a biological standpoint, most processes related to light depend on frequency dependent photon density counts over time. While some relationships are related to total energy, expressed in wattage, or the polarization of light, other forms of measurement are too general and unrelated to allow a researcher or keeper to make any repeatable observations and so informed judgement about lighting and husbandry care. Questions of proper measurement are true across the three ZLI research milieux, even if statistical studies are helpful to stress impacts of artificial light or glass in general.

Without belaboring a recount of such alternatives here, many of which have a pseudoscientific 'feel' to them but never had the intent of scientific study, suffice it to say that a wealth of technical alternatives is really no wealth at all.

Physiological studies generally require a spectra-radiometer to measure in terms of photon density counts over time, or wattage if one is studying radiant heat. Sensory ecology also depends upon the frequency distribution and photon counts, in addition to further consideration of how the particular eyes or other light receptors in an animal function. For example, it may be that the flicker rate of light is important to inducing certain reactions in an animal, something that could potentially become very important if artificial light say from a video monitor or ballast induced fluorescent lamp is present in an exhibit or habitat. In terms of partitioning, one might ask how population densities or activity timing requirements might change at different illumination levels or due to the shape of light. As answers to each of these questions must be species specific, exact parameters will vary but the point is, research exists to guide further inquiry.

The purpose of ZLI is after all to link independent research to the practical matters of animal care and wildlife conservation.

***Culture always informs the scientific method.*** Science as a method is always related to culture, particularly when science is free from posing as a culture itself. Culture enters into the scientific method as a person or group of people make observations, pose interesting questions and formulate hypotheses as to causes and the structure of conceptual patterns. If I chose to care for animals, or protect the viability of the environment around a community, these are cultural decisions. Such decisions may provide clues as to how a research community thinks and acts.

When researchers make observations, pose questions and attribute causes for perceived phenomena, it is impossible to ignore the vantage point from which such propositions are made. A diversity of vantage points is vital to advance science, for without such diversity no interesting questions could be asked. General theories would become both static

and dogmatic, limited by limited experience and language inherent to the postulation of questions. General theories, such that one might associate with occidental concepts of light and dark for example, would and could never receive the challenges necessary for scientific advancement without vibrant engagement from many quarters.

This is a point very important to stress as it relates to the international character and aspirations of The Zoological Lighting Institute. Predictions within the scientific method of necessity based upon culturally bound hypotheses, must be amenable to alteration, refinement and rejection for the method to be scientific. General theories gleaned from this method based upon data must be also considered cultural, leading to new observations, questions and hypotheses. General theories do not substitute for the scientific method as a whole, and are always within the framework of the scientific method subject to critique and rejection. Any rejection that comes to invalidate an existing general hypothesis arises from within the method itself, based upon data relevant to the hypothesis. One might well ask if there is one science or many, if sciences overlap, or if a contradictory hypothesis is sharp enough to kill off an entire general theory. Though the scientific method cannot be considered to be a culture, (to do so would violate its primary tenant within which general theories are subject to rejection in ways that a given culture is not), it draws life from the diversity of cultures inherent to civil discourse and indeed, humanity.

Although this detour into the value of diversity for science and ZLI may seem to be far afield from the subject of managing the luminous environment in aquariums and zoos or in the field, it is highly relevant. Such engagement leads to improved insights, observations and hypotheses, subject to the rigors of logically bound experimentation.

## Enriching, rather than replicating, a 'Luminous Environment'?

Natural light is an integral part of wildlife habitat. It has shape, qualities and intensities that vary in regular cycles over time, subject to certain fluctuations such as fires and lightening or other local occurrences such as bioluminescence and the reflectivity/absorption of organic and inorganic materials. Providing a completely natural luminous environment in managed care is impossible, but that does not mean that science cannot create a luminous enrichment scheme to account for relevant differences between *in-situ* and *ex-situ* conditions.

***The first step*** in any program is to establish a system to measure light quality over time, in regular intervals. A spectra-radiometer is a more important device to purchase than any light fixture or control system. Yet even a digital SLR camera can provide valuable histogram data to understand the overall picture of the luminous environment in a given exhibit space.

Before adopting standardized levels or protocols, it is necessary to first understand conditions more thoroughly. Photobiology research is currently inadequate to answer the questions that aquariums and zoos must pose, as *ex-situ* facilities dedicated to and capable of exploring species-specific hypotheses impossible to do in the field with certainty. A best case scenario would link *ex-situ* with *in-situ* studies, and so to arrive at plausible general theories capable of advancing care.

***A second step*** is to pay close attention to the luminous properties of available materials, including holding areas and on-exhibit spaces alike. This includes air qualities, such as humidity or fog, and more solid elements such as plants, glass, cement, earth and water. Local materials create very different luminous environments, something easy to remember when one considers that the self-same sun casts illumination upon deserts and rainforests alike. How well the reflective properties match an *in-situ* condition, has a far greater effect on the lighting of an exhibit than often considered.

***The third step*** is to consider what unintended radiant light is present in an exhibit. Is there illuminated signage present, including exit signs? Are there unintended LED signal lights that nevertheless can be seen from an exhibit space? Do lights designated as 'service' lights impede the luminous environment of an exhibit, and fall outside 'exhibit lighting' consideration? Are there 'black box' areas of an exhibit that admit no light, and so might offer a looming threat? Animals tend to function at much lower light levels than humans, and so over-exposing a digital image of a space is one good and quick way to judge immediate degradations in an exhibit.

***The fourth step*** is to consider where general illumination enters a space, or rather what is the shape of light in an exhibit? One can take this to a more holistic level through a very specific point. How for example, does the horizon to sky gradient look in the exhibit or holding area? Typically such profiles are inverted from their natural conditions. It is a simple question, but attending to the visual profiles of exhibit spaces improves the 'luminous environment' drastically. Remedial steps might include a paint job to brighten the sky, or screening/shielding low windows at the perimeter.

***A fifth step*** is then to consider the timing of light. If one enters the space at night, and there are service lights, exhibit lights, exit signage or machinery lights still on, there is a problem. Natural light operates in cycles, and if a static condition is imposed either in the night or day, animal physiology, sensory ecology and activity partitioning will suffer. Although for over a century, aquariums and zoos have done a wonderful job in providing amble daylight for managed animals, it remains a concern as not all daylight is equal. Today of course the more pressing problem is added artificial lighting at night, but the provision of UV light for animals relocated from one part of the globe to another, or that are held in interior spaces which rarely receive UVa or UVb, remains a problem.

Before touching upon the selection and use of specific fixtures themselves, this point is very important. Of the three ZLI research milieux, perhaps the least attended to in managed care, is ironically sensory ecology. Many species use UV light to map the space about them. Yet unless dedicated UVa is provided in an exhibit or holding area during the day-time, it is as if the animals wear colored sun glasses that restrict the full range of their visual sensitivity. No one of course, would do this consciously, but the unintended lack of UVa in aviaries (or indeed most managed contexts) does just that.

Whether or not this results in measurable stress is irrelevant, as the purpose of enrichment schemes is to allow an animal to perform as full a range of natural behaviors as possible in managed care. Vision is an integral part of such behavior, and must be considered as a biological function imperative to the well-being of animals. The less one needs to 'enrich' in managed care due to the inevitable changes brought on by relocation, the better. UVa needs to be provided, and addressing the luminous environment through this fundamental aspect of visual ecology ought to change every aviary and diurnal exhibit across the globe.

This point emphasizes the need for spectra-radiometers, because there are photo-biological relationships due to frequencies and frequency relationships that humans simply don't 'see' and so don't recognize the importance. The luminous environment changes over time in humanely imperceptible ways, and yet has a great impact on the health, sensory abilities and activity spacing/timing of wildlife.

***The sixth step*** is often where most people begin when thinking about lighting; the purchase and maintenance of lighting fixtures. The situation is understandably confusing, with so many lighting products being marketed as environmentally friendly and energy efficient. As a point to remember, the most efficient light is natural light, though natural light may require supplementation to meet the needs of animals relocated from one area of the globe to another, or maintained in an internal space with no access to natural sky/sunlight or that display different reflective properties from natural conditions. *Do not, as a point of emphasis, purchase unnecessary lighting to stress energy savings or green practices, when the cheapest and least polluting light is available in the form of natural light. Less is more.*

This sequence of steps leads to a suggested protocol for aquariums and zoos. 1) Measure light quality over time. 2) Pay close attention to the luminous (reflective, transmitting and absorptive) properties of materials in an animal space. 3) Ask what unintended images are visible

from within an animal area, at all hours of night and day and then 4) what general illumination enters a space at all hours of night and day. 5) Ascertain the appropriate timing of light for the particular species of animal held in care. Only after these considerations, which ought to be substantiated by round the clock data driven measurements in appropriate physical terms ((photon flux density) binned per frequency) should 6) control systems, lamps and lighting fixtures be specified for an exhibit..

In order to select fixtures, there are several key considerations. Rethink what supplemental artificial light is necessary for a particular animal in your facility to most closely address habitat needs emanating from its indigenous environment, from starlight to full sun. Restraint is your friend. It should be complemented by shading opportunities, as has long been standard practice in exhibit design.

## General Lighting Technology Considerations

Artificial Lighting is a just that, artificial. Because of this, decisions made about it entail a process of limitation and extraction from natural experience. It is impossible to reproduce a natural luminous environment or to recreate 'natural light'. Claims to the contrary are misleading at best, or outright harmful at worst. Added artificial light ought to be remedial, medicinal and considered to be an integral form of enrichment.

"Behavioral enrichment, also called environmental enrichment, is an animal husbandry principle that seeks to enhance the quality of captive animal care by identifying and providing the environmental stimuli necessary for optimal psychological and physiological well-being.[1]" Complex, image-forming eyes evolved independently some 50 to 100 times[2], having first evolved in the rapid burst of evolution known as the Cambrian explosion[3]. This is important, because it stresses the fact that the manipulation of the optical environment is a crucial aspect of life, and one central to a wide range of activities including foraging, breeding, rearing and inter-species interaction. Without light there is no life, and without wildlife there is of course, no life.

There is a rather odd process in specifying lighting for environmental enrichment. Although physical light is ultimately our main concern, artificial lighting systems themselves evolved as a limitation of natural conditions. Compared to the complexity of natural light, the bright lights of Broadway are monotonous. Natural light exists from cloudy starless night to full sun, emanating from countless rotating stars in addition to the dominant daytime movements of sun and sky. Artificial light narrows this experience to a very small range, cutting out dynamism and range in favor of a steady-state condition. This observation changes the ways in which light fixtures ought to be specified.

The first consideration in specifying lighting equipment for an exhibit is to consider control systems. When should a particular light quality be radiated into an exhibit and why? Access to sun and sky provide access to dynamism, but only if such light is not washed out (particularly at night) by an added steady state condition. How and when added artificial lighting equipment is applied in an aquarium or zoo matters a great deal to the viability of animals in its care.

Lighting can be switched or dimmed, and each either locally or from a remote location. Controls can be manual or automated to respond to timing, motion or theatrical requirements. Each depends not only upon the animal under enrichment care, but also to the flexibility of operational concerns.

The main challenges for an institution in deciding what lighting controls are appropriate, are akin to deciding what goals are appropriate to mission planning. Luminous enrichment is often disregarded, but we would argue that the naturalistic display of healthy animals capable of performing their abilities to the fullest extent possible is a core value. This doesn't mean that other concerns that often demand contextually inappropriately high levels of artificial light are to be ignored, such as facility maintenance or informative exhibit graphics, but rather that they are to be accomplished in ways that do not degrade the luminous habitat.

Selection of control systems should come first before the selection of light fixtures in our industry, but then should be re-examined after lighting fixtures designed to deliver appropriate artificial supplementation have been chosen. Although we suggest selecting control systems first, it is to be understood that at the end of the day it is the light itself in an exhibit that is important. Control systems allow consideration of lighting shape, and light fixtures qualities. Some qualities can only be provided by certain types of lamps that require certain control systems. Some light fixtures, such as fiber optic systems, OLED and integrally-controlled LED systems, can also make separate control systems redundant. Regardless of the natural back and forth process, such requirements ought to be established by environmental enrichment needs, rather than as a by-product of a general technological capability.

After deciding when and how light supplementation is important for particular species, and so what control systems might be relevant for a particular exhibit, one can then turn to lamp selection.

## Available Lamp Types

In considering the various means to artificially and electrically supplement the luminous environment in aquariums and zoos, a person will find several choices on the market. These include incandescent, halogen, fluorescent (compact and linear), metal halide, LED and (HID) Plasma. Each has different properties, which ought to be understood.

As mentioned earlier, the most important lighting equipment in managed animal care is a spectra-radiometer, to measure the actual light available in an exhibit. Many factors go into the overall luminous environment that are not discernible to simple perception or expectation due to product specification. Data driven measurements offer the basis for decision making, and even a hand-held spectra-radiometer can allow for useful data to be recorded.

Many measuring systems are on the market, and a word regarding some typical criteria ought to be helpful. Lamp manufacturers generally list color temperature in kelvin (K°) and lumen output being the main culprits. These are not useful for animal care purposes due to very specific issues.

Lumens are based upon retinal human sensitivity during diurnal conditions. Even in this context it relates very little to how humans create visual images from retinal information, or how people are able to map, navigate and discriminate objects in space. One measured lumen may actually contain light of any frequency, combined in proportions that are impossible for a researcher to extract from the data given. For this reason, a study based in lumens tells one nothing of how the physiology, senses or activities of an animal (with differing sensitivity curves), or a human-animal (which may be responding to a variety of different factors present within the same inappropriate measurement).

Color temperature has a similar issue. Typically one will find color temperature in a range between 2500°K and 6500°K, with much

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higher values for aquarium lights available. Such temperatures relate to the relative color warmth of the lamp, from reddish orange of incandescent lamps to the cold blue of a specially designed metal halide or fluorescent.

Although laudable light pollution mitigation groups will recommend using warm lights outdoors to prevent skyglow and melatonin suppression, the situation is actually more complex. Warm lighting may very well contain relatively low in proportion higher frequencies (colder, bluish appearing light), it might still emit amounts significantly higher than natural levels. While human vision may not pick this up, organic material and most animal perceptual systems certainly can.

This means again that a true spectral profile from a spectra-radiometer is crucial to understanding the environmental enrichment of animals in managed care. While the specific measurements taken depend upon the particular biological process studied, it is important in all cases to return to physical, rather than industrial, optics.

There are other practical concerns to consider as well, beyond misleading measurement protocols. The actual light emitted by lighting fixtures is inevitably less than anticipated. Light loss factors include an ambient temperature factor, a heat extraction thermal factor, a voltage to luminaire factor, a ballast factor, a ballast-lamp photometric factor, an equipment operating factor, a lamp position (tilt) factor, and a luminaire surface depreciation factor. The light output of lamps depreciate over time, and they slowly burnout.

Lights and the spaces they illuminate get dirty over time. Dirt changes the amount and quality of light added to an exhibit. Dirt may be generated in the space itself, it may be carried into the space from elsewhere, and it may adhere to different parts of lighting fixtures so that emissions differ radically from what they are supposed to provide. It also matters how the air in such spaces is filtered or otherwise removed. Measuring light allows a researcher or keeper to know exactly what a hosted animal faces on a daily basis.

That being said, different lighting sources have different properties that are useful to understand in an animal enrichment/management scenario. Although one can find plenty of information on lighting technology in brochures, text books and the internet, it is hoped that the following is useful.

### *Incandescent lighting*

General Description:
Incandescent lights produce light by heating a filament electrically. Burning the filament in this way produces a continuous output of photon frequencies across the visible spectrum. These frequencies may be emitted in different proportions depending on how hot the filament burns or how the initial emission light is filtered by intervening glass. The smooth emission of frequencies can be important, as relates directly to the qualities inherent to sun-light, reflected sunlight off the moon and earthly light emissions such as fire.

Advantages:
Incandescent/halogen lighting can be very useful, and has been employed particularly for herpetological applications where irradiant heat is necessary for the overall care of the animals. Furthermore, as incandescent/halogen can be dimmed easily and as there are many lamp shapes available to customize an exhibit design, it is possible to employ light as a point source. Typically halogen/incandescent lighting is used for spot lighting, which can be useful to provide a controlled range of lighting shapes in an exhibit. Incandescent/halogen lighting fixtures also can be fitted with filters, which can further increase the options available to a keeper to modify lighting conditions in an exhibit.

Disadvantages:
Because light and heat are combined, it can be a challenge to use incandescent and halogen lamps effectively where only one factor or another is more important than the other. This can be overcome by using fiber optic cables connected to remote lamps, which have the added benefit of including integral filters and very precise lighting profiles within an exhibit. With a short lamp life and significant heat generation though, incandescent lamps have to be used very carefully and proactively for specific applications.

### *High-intensity discharge lighting*

General Description:
Mercury, high pressure sodium and metal halide lamps are high intensity discharge lamps. These contain an inner capsule with either argon, xenon and/or neon as starter gasses, along with a fractional amount of metals or metal halides. It is the latter that give a high intensity discharge lamp its characteristics, that is to say what frequencies of light it emits.

Advantages:
As the name implies, high intensity discharge lighting can be very powerful. This means that they are very useful in providing adequate amounts of light at greater distances, including ultraviolet.

Disadvantages:
It is very difficult to manufacture HID lighting to exact specifications, due to the minute amounts of metal/metal halides present. This means that HID fixtures will vary from lamp to lamp in the exact amount of light they provide. Furthermore, they cannot be dimmed and so it is difficult to adjust lighting conditions, either due to varying environmental concerns or over time.

### *Fluorescent lighting*

General Description:
Fluorescent lamps emit light after ultraviolet radiation created by an electrical discharge passed through mercury vapor excites a variety of phosphors. A typical fluorescent lamp will contain, in addition to mercury vapor, a variety of phosphors that will emit a range of light frequencies useful for different applications. This light is 'discontinuous', meaning that it cannot not render environmental colors in a way reminiscent of daylight/moonlight but will rather always leave something out.

To limit the amount of electricity passed through the mercury gas, fluorescent lighting requires a 'ballast'. Ballasts are used to ignite the mercury vapor, and to limit induced current to prevent an overload. Ballasts can be of two types, magnetic or electronic. Magnetic ballasts tend to have a lower power factor, meaning they are less efficient than electronic ballasts that can use up to 90% of the power supplied to them. Magnetic ballasts are also subject to flicker and an audible buzz. They are still to be found as they are quire simple in construction and generally cheaper, but should not be employed in animal spaces. Both types of ballasts can be installed 'remotely' if necessary on a separate tray.

Advantages:
Fluorescent tubes have long been used for general lighting and have been tailored to address animal care requirements in the home pet market. Specifically, they have been used to provide UVa and UVb in addition to human visible light frequencies to care for birds, corals and reptiles. The availability is good for keeping the costs of supplemental down and in connecting into typical architectural and lighting design practices. Fluorescent lamps typically last much longer than incandescent or halogen lamps, meaning that maintenance costs will be lower. They can also be filtered and dimmed using gels fitted around the lamps themselves, as well as through the use of specific dimming ballasts.

Disadvantages:
Fluorescent tubes contain mercury vapor, and so are classified as an environmental hazard. Proper care is needed when disposing of them. Although the lamps themselves have a long life, it is important to remember that the ballasts as well as the lamps require attention. Dimmable ballasts are available, but must be specified to coordinate with control systems.

Typically, fluorescent lamps do not provide the kind of output needed to provide significant levels at great distances, or through appreciable depths. Because of this, high intensity discharge lamps often supplement fluorescent lighting in exhibit design.

### *LED lighting*

General Description:
These have become very popular over the past decade (2000s), and an industry standard after a slow and troubled start. An LED light emits light as electricity passes over

Advantages:
The strength of LED lighting is in the control it offers. it is very possible to select LED lighting sources that emit a very narrow range of light frequencies. This is important for enrichment schemes and for research, as they allow for exact provision of very specific criteria if selected appropriately.

Disadvantages:
LED sources that utilize phosphors to produce lighting have to be monitored very closely. Much of the efficient lighting that is sold on the market is highly inappropriate for use at night, in that it provides far too much light in the 450-500nm range. Such emissions have been shown by the AMA to disrupt melatonin cycling, and this applies for humans as well as animals. It is also so for interior and exterior applications alike.

Another issue with LED lighting arises from the relatively small point source they present. This is a challenge in that the glare produced is considerable, and that the contrast between the point source and the surrounding (darkened) area creates visual stress. Also, due to the high content of 'blue' lighting (higher frequency), is long-term damage to retinas.

Finally, ultraviolet lighting provided by most commercial LED lamps does not have enough strength to be effective in many situations.

### *HEP Plasma Lighting*

General Description:
Plasma lamps generate light by exciting plasma using radio frequency (RF) radiation rather than ultraviolet, qualitatively indistinct from visible light. Subsequently excited electrons fall back to original states and in so doing emit photons. This results in visible light or ultraviolet radiation, depending on the fill materials. HEP lamps have a long operating life, and emit a spectral profile closer to sunlight than other sources.

Advantages:
HEP (High Efficiency Plasma) lighting has come onto the market fairly recently. It has the advantage of producing an enormous amount of light concentrated in a very small source. This brightness can be very useful, to put quite a lot of light into the depths of an aquarium exhibit for example. HEP lighting is also used for grow-lights, as a typical spectral profile approximates a continuous distribution of frequencies.

Disadvantages:
The disadvantage of HEP lighting relates to its strength... they are incredibly bright. This means that night time lighting can limit natural nocturnal environments in unprecedented ways, and also that there exists a very high likelihood of glare and 'blue-light' hazard (damage caused by high intensity high frequency light). In a terrestrial or aquatic animal setting, this means that it is very possible to functionally blind animals due to the brightness, and to mis-cycle hormones due to inappropriate lighting levels at night.

## Final Remarks

Lighting in managed care is vital to attend to, as it improves the very mission of aquariums and zoos to unite animal care with wildlife conservation. To close, we ought to reiterate the steps:

1. Measure light quality over time.
2. Pay close attention to the luminous (reflective, transmitting and absorptive) properties of materials in an animal space.
3. Ask what unintended images are visible from within an animal area, at all hours of night and day and then
4. what general illumination enters a space at all hours of night and day.
5. Ascertain the appropriate timing of light for the particular species of animal held in care. Only after these considerations, which ought to be substantiated by round-the-clock data driven measurements in appropriate physical terms (photon flux density) binned per frequency, should
6. control systems, lamps and lighting fixtures be specified for an exhibit.

Light pollution degrades habitat, an issue whose significance has barely begun to be appreciated. The more that aquariums and zoos pay attention to light and celebrate photobiology to the public, the better our environments will be. Zoo keepers are of course invited to become members of The Zoological Lighting Institute at www.zoolighting.org to apply for scholarships and to protect animals and their ecosystems from a most hidden challenge to wildlife conservation.

# Learning from Reptiles:
## Herpetological lighting basics and applications for all zoo animals

Shane Bagnall
Zoo Med Laboratories, Inc.

In the earliest days of zoo reptile husbandry, reptile lighting generally consisted of lamps used to provide heat. Groundbreaking research by Cowles and Bogart in the 1940's provided the herpetological community with a better understanding of the thermal requirements of reptiles, and zoos used this information to create preferred optimum temperature zones, or POTZ, in reptile habitats. While knowledge of the relationship between ultraviolet light, vitamin D, and reptile husbandry existed since at least 1952 (Brattstrom), specialized UV lighting was not readily available and sunlight remained the only reliable source of UVB lighting. A breakthrough occurred in 1969 when zoo herpetologist, Joseph Laszlo, published an article on the use of fluorescent lamps with reptiles. While commercial UVB lamps for reptiles were still unavailable at this time, the lamps used did emit UVA light which is beneficial for reptile vision and behavior (see glossary for descriptions of UVB and UVA with respect to reptile husbandry). During this time, it was still difficult or impossible to house many reptile species indoors year-round as they would develop nutritional secondary hyperparathyroidism, the most common form of reptilian metabolic bone disease due to the absence of UVB light. It wasn't until 1993 that the first commercial UVB lamp for reptiles was introduced. This groundbreaking product made it possible for the first time to successfully house many species of reptiles indoors year-round.

When considering lighting for zoo animals other than reptiles, often the main concern is to provide an appropriate photoperiod. Much of the fauna in zoos spend their time in open, outdoor habitats with access to natural lighting provided by the sun. For these animals the sun provides a full spectrum of light to illuminate the habitat, warmth through infrared radiation, and a natural photoperiod that changes according to the season and latitude. Artificial light sources come into play for animals that spend all or part of their lives in indoor housing without access to natural sunlight.

For the large number of zoo animals housed indoors for all or part of the year, their mental and physical health is largely dependent on having access to proper lighting regimens. At the time of writing, there are twenty-four completed AZA Animal Care Manuals covering everything from Jellyfish to Polar Bears. When reviewing the Animal Care Manual template, there is a section devoted to lighting which includes guidelines for the spectral needs, intensity, and duration of lighting regimes for each species or group. Two major lighting themes covered in these manuals are seasonal photoperiods and full spectrum lighting.

### The importance of photoperiods:

When animals are housed indoors, supplemental habitat lighting is typically required. This is especially true when indoor housing is void of any windows to provide a photoperiod from incidental lighting. Nearly all of the AZA Animal Care Manuals recommend provisions for seasonal changes in photoperiods consistent with the animals' home range. One main reason is to elicit reproductive cycles and behaviors that are only triggered through changes in day-length. In addition to reproduction, circadian rhythms are important for numerous biological processes, including feeding and sleeping patterns, hibernation, and neurological functions.

### Sources of light in zoo habitats:

Lighting found in zoos can be broken down into three distinct categories; *natural lighting*, *ambient lighting*, and *habitat lighting*. Natural lighting includes direct or shaded access to full sunlight. Ambient lighting is incidental lighting that illuminates living spaces through one of two means: filtered lighting through windows and other openings (like skylights), and artificial lighting for which the primary purpose is not to illuminate the habitat (like ceiling-mounted fixtures for general room lighting). Finally, habitat lighting refers to artificial lighting for the primary purpose of illuminating the animals' habitats for one or more reasons:

- Lighting the habitat for public viewing.
- Using lamps to raise the ambient temperature in all or part of the habitat.
- Using lighting to provide the proper photoperiod for a given species.
- Lighting to provide for animal health with respect to photobiological processes, mainly cutaneous biosynthesis of vitamin D upon exposure to UVB.
- Lighting to allow animals to see their environment as it likely appears to them in nature. Many animals possess the ability to see things illuminated by UVA wavelengths. For these animals, habitat lighting should have emissions within the UVA region of the spectrum.

### The many faces of full-spectrum lighting:

With reference to artificial lighting, the term "full-spectrum" can have several different meanings. The electromagnetic spectrum describes the wavelengths generated by the sun with shorter wavelengths producing X-rays on one end, longer wavelengths producing radio waves on the other end, and visible light in-between. Typically, the wavelengths in the visible region are associated with the "human visible" spectrum. Animal vision is highly variable, and the visible spectrum can vary greatly from one species to the next. Before going further, it is important that when this term is used here, full-spectrum refers to lighting that generates "human-visible" light, ultraviolet A (UVA), and ultraviolet B (UVB). Unfortunately, the term is often used to refer to lighting that includes human-visible wavelengths, in addition to UVA light, but not UVB. This has led to confusion over which lamps are appropriate when "full-spectrum" lighting is specified for animal husbandry.

### Who needs UVB?

Keepers with even a basic understanding of the lighting requirements of reptiles know that most reptiles require exposure to UVB lighting along with an appropriate thermal gradient in order to meet their vitamin D needs. Animals in general meet their vitamin D requirements through two pathways: dietary and/or photobiosynthesis. The latter refers to the process in which vitamin D is synthesized in the skin upon exposure to UVB and heat. It is then metabolized into different forms in the liver and kidney. These vitamin D metabolites are responsible for maintaining normal blood-calcium levels. Without sufficient vitamin D, dietary calcium passes through the intestines unused, and bone-stores of calcium are depleted as calcium is critical to numerous cellular processes. Left uncorrected, this problem leads to a form of metabolic bone disease that results in soft, rubbery bones, inability to move normally, organ failure, and ultimately death.

One might then ask the question; Why not just provide reptiles with dietary vitamin D instead of using specialized UVB lighting? While this approach might work for some reptile species, it fails with many others. As a general rule, the dietary requirements of reptiles give clues as to which species are able to utilize dietary vitamin D. There are over 10,000 different species of reptiles that have evolved to exploit a variety of different food sources throughout the world. Some reptiles are obligate carnivores, and exist on a diet of whole, vertebrate prey. Others are obligate herbivores and eat only plant material. Many others are insectivorous, omnivorous, frugivorous, etc.

When a snake eats a mouse or rat, it is supplied with the vitamin $D_3$ metabolites that are stored in the prey's liver. Another name for vitamin $D_3$ is cholecalciferol, and this name is often found in the ingredient listings of many commercially produced zoo diets. Since snakes ingest vitamin $D_3$ as part of their natural diet, they are generally able to meet their vitamin $D_3$ needs through dietary means. Many tortoises on the other hand eat a diet of primarily plant material. Plants contain a precursor to vitamin $D_2$ which is less effective at preventing metabolic bone disease than vitamin $D_3$. Plants also lack skin, liver, and kidneys, and consequently also lack vitamin $D_3$. For these reasons, herbivorous reptiles rarely encounter vitamin $D_3$ in nature and are unable to adequately metabolize dietary vitamin $D_3$. They rely almost exclusively on UVB to meet their vitamin D needs. It could be said that they are *obligate photobiosynthesizers*. Some insectivorous species also fall into this category.

In spite of the fact that carnivorous reptiles seem to be able to live a life absent of any UVB lighting, researchers questioned this practice. Upon exposing snakes to UVB, it was found that they possess the biological mechanisms that allow them to synthesis vitamin D in the skin (Acierno et al., 2008). Since many of these species are diurnal or crepuscular,

## DESCRIPTION OF THE FERGUSON ZONES


### FERGUSON ZONE 1: UVI 0.4 TO 0.7
*(Shade/Crepuscular)*

Species in this zone can be either diurnal (active during the day) or crepuscular (active at dawn or dusk). They avoid direct sunlight exposure and are able to meet their vitamin D requirements through exposure to low levels of UVB typically found in the shade, or at dawn or dusk.

**NOTE:** *In the original study by Ferguson, et al., Zone 1 ranges from 0.0 to 0.7 UVI. For the purpose of reptile husbandry, 0.4 is given as a minimum as this has been shown to be effective in providing for a healthy vitamin D condition in Zone 1 species.*

### FERGUSON ZONE 2: UVI 0.7 TO 1.0
*(Mostly partial sun/Occasional full sun baskers)*

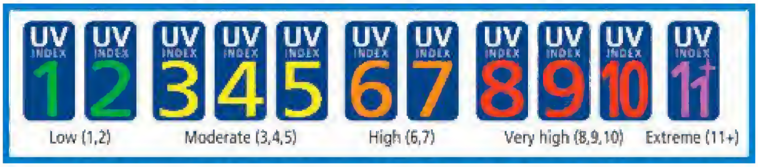
This is a small range that is very close to Zone 1, but species in this zone will occasionally venture out into full sunlight for short periods of time.

### FERGUSON ZONE 3: UVI 1.0 TO 2.6
*(Mostly full sun/Occasional partial sun baskers)*

Zone 3 covers a fairly broad range and includes many species common to herpetoculture. These temperate, tropical, and sub-tropical species will bask in full sun early in the day or early afternoon. During mid-day, they may be found basking when conditions are partly cloudy. With zone 3 and above, it is **VERY IMPORTANT** to provide a UVB gradient down to zone 1 UVB levels so that reptiles can "photoregulate" and adjust their UVB exposure as needed. Failure to provide a UVB gradient can result in illness, eye and skin damage, or even death.

### FERGUSON ZONE 4: UVI 2.6 TO 3.5 OR MORE
*(Mid-day full sun baskers)*

Zone 4 species would include the majority of "desert" species that bask in full sunlight, even after Zone 3 species have retreated into burrows or the shade. **IMPORTANT:** Just as with zone 3, it is critical that the habitat is large enough to provide a UVB gradient down to zone 1 levels to allow reptiles to photoregulate and adjust their UVB exposure. Failure to provide a UVB gradient can result in illness, eye and skin damage, or even death. Avoid UVI levels of 8.0 or more for zone 4 species as even the most sun-loving reptile species retreat from full sunlight at these high levels.




*UV Index scale*: The UV Index scale with ranges based on human UV exposure.

they receive exposure to UVB in their natural habitat. Other studies revealed that nocturnal geckos are very efficient at synthesizing vitamin D in the skin with only the little UVB they receive just before the sun sets (Carman et al., 2000). Studies like this led many to reevaluate best practices with respect to UVB lighting and reptiles.

In recent years, insightful zoo personnel have implemented UVB lighting programs for animals other than reptiles and amphibians. This is evidenced by the fact that one third of the aforementioned AZA Animal Care Manuals recommend access to UVB for vitamin D synthesis in birds, mammals and reptiles. This approach to zoo lighting follows the principle that if an animal receives UVB in its natural environment, we should provide that animal with access to UVB in an effort to recreate their natural habitat in the zoo setting.

### How much UVB is appropriate for various species?

The earliest UVB lamps for reptiles provided relatively low levels of UVB that approximated the amount of UVB they would be exposed to in the shade or on a cloudy day. These low levels turned out to be safe and effective for many species of reptiles housed in traditional reptile enclosures. They provided not only UVB and UVA, but also a photoperiod as they could be left on for eight to twelve hours without risking excessive UVB exposure. In later years, stronger UVB lamps became available that provided "direct sunlight" levels of UVB in the habitat. These lamps required larger habitats that offered a UVB gradient, allowing reptiles to photoregulate and adjust their exposure to UVB. Similar to humans, excessive levels of UVB can cause skin and eye damage in zoo animals. A reliable method for evaluating UVB lamps and their use in animal husbandry was urgently needed.

UVB meters have been used to measure reptile UVB lamps for decades, and attempts have been made to translate meter readings to husbandry recommendations. These attempts often fell short due to the fact that the meters used did not allow for direct comparisons between different types and brands of UVB lamps because of the lamps' differing spectral outputs within the UVB range. Two different brands of lamps might produce the same reading at a given distance but one of the two could be much more effective at promoting vitamin D synthesis than the other. Additionally, the meters did not allow direct comparison between any lamp and natural sunlight which typically produced much higher meter readings than the lamps. These broadband UVB meters are effective at identifying whether or not a lamp is emitting UVB, and also allow the user to track UVB decay over time, but they are not ideal for identifying the ideal placement of UVB lamps in animal habitats.


***UV Index meter*:** Because of the calculation used to create the UV Index, this meter allows for direct comparisons between different types and brands of UVB lamps, and also between lamps and natural sunlight.

A breakthrough in understanding how to measure lamps for use with reptiles came when a team of researchers used a handheld UV Index meter to measure and evaluate UV levels that wild reptiles were receiving in their natural habitat (Ferguson et al., 2010). The UV Index is an international scale used to measure UV radiation from sunlight. This scale proved to be ideal for measuring reptile UVB lamps and paved the way for identifying appropriate UVB levels for various species. The UV Index uses the erythemal action spectrum in its calculation which is a weighted response curve that measures the potential for skin damage upon exposure to radiation. Conveniently, the vitamin D action spectrum is nearly identical to the erythemal action spectrum, making the UV Index a useful tool in evaluating UVB sources and their ability to promote vitamin D synthesis in animals.

The UV Index uses a color-coded chart and has recommendations for human UV exposure. This scale covers a range from 0 to 11 and up. Since the index was created for humans, it recommends wearing clothes, applying sunscreen, and limiting the times and duration of UV exposure to avoid sun burn. Clearly this scale was impractical for animal husbandry. If the UV Index was going to be used to evaluate UV sources and their application in herpetoculture, a modified scale was needed.

Using the UV Index, Ferguson identified four distinct zones of increasing UV intensity based on observations of reptiles basking in nature. These zones became known as the Ferguson Zones and provided a solution to the human scale issue described earlier. On the low end of the scale, zone 1 is associated with species that are crepuscular and/or only receive UVB in shaded areas. On the upper end, zone 4 describes species that bask for long periods of time in direct sunlight. A detailed description of each is highlighted, as described in the UV Index meter instruction manual (Zoo Med, 2013). In his research, Ferguson found that when UV Index levels reached eight or higher, even the most sun-loving species retreated for cover. This provided an upper safe limit for making recommendations on appropriate UV levels for reptiles. Using a UV Index meter, UVB lamps can be easily and quickly measured to determine if the UV intensity is within the appropriate zone at the animals' basking site.

Following this initial work on reptiles and the UV Index, studies relating to photoherpetology now often include UV Index data. One of the authors of the original Ferguson study, Frances Baines, published a follow up

## GLOSSARY OF LIGHTING TERMS

**UVA (Ultraviolet A):** The wavelengths of energy within the electromagnetic spectrum between 315 and 400 nanometers. The visual spectrum of some animals extends into the UVA range.

**UVB (Ultraviolet B):** The wavelengths of energy within the electromagnetic spectrum between 280 and 315 nanometers. Wavelengths in this range contribute greatest to the biosynthesis of vitamin D in animals. Wavelengths below 290 are dangerous and are filtered by the earth's atmosphere. These wavelengths are considered non-terrestrial UVB as they do not reach the earth's surface.

**UVI (UV Index):** A unitless index that was created to measure the intensity of ultraviolet radiation from sunlight and is based on the sun's potential to cause sunburn in humans.

**Ferguson Zones:** Four zones based on the UV Index associated with the photoregulatory behavior of reptiles.

**Photobiology:** The study of the effects of light (or photons) on living organisms.

**Photoherpetology:** The study of the effects of light on reptiles and amphibians.

**Photoregulate:** The behavioral adjustment of body location or orientation with respect to light.

**Herpetoculture:** The science of reptile and amphibian husbandry.

study identifying UV Index zones for hundreds of species of reptiles and amphibians (Baines et al., 2016). For the first time since specialized UVB lamps were released over 30 years ago, we now have an effective tool for validating UVB lamp arrangements used in reptile and amphibian husbandry. As mammals and birds also possess the mechanism for biosynthesis of vitamin D upon exposure to UVB, insightful keepers have been adapting reptile UVB lamps for use with mammals and birds for many years. Since basking behavior and UVB exposure as described by Ferguson can be attributed to nearly all zoo animals, the Ferguson Zones can be used to identify baseline UVB and lighting recommendations for zoo animals other than reptiles and amphibians. Further research and documentation of basking behaviors and UVB exposure for all zoo animals, *in situ* and ex *situ* is recommended.

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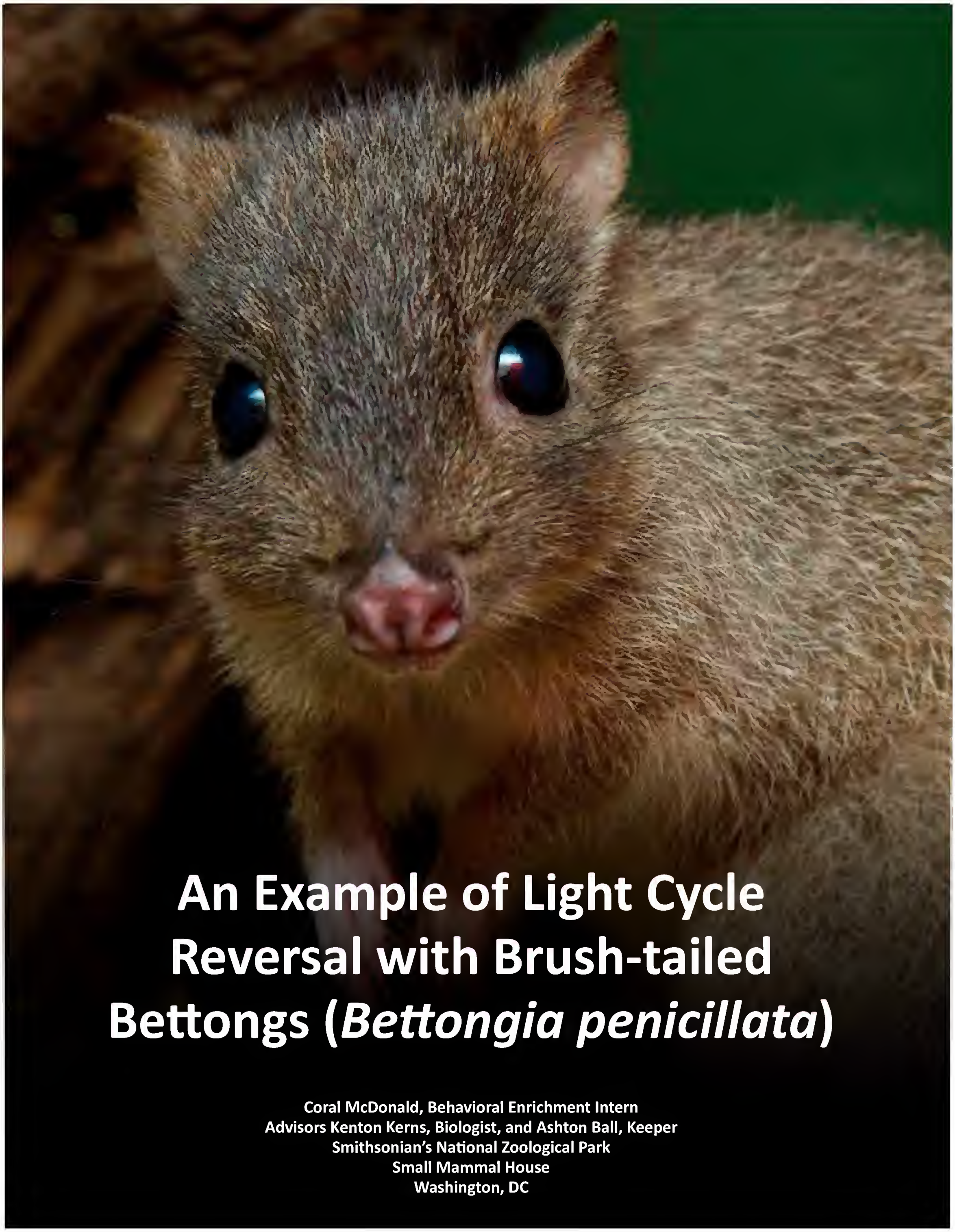

# An Example of Light Cycle Reversal with Brush-tailed Bettongs (*Bettongia penicillata*)


Coral McDonald, Behavioral Enrichment Intern
Advisors Kenton Kerns, Biologist, and Ashton Ball, Keeper
Smithsonian's National Zoological Park
Small Mammal House
Washington, DC

## Introduction

Zoos provide visitors with rare opportunities to view endangered animals and learn about conservation efforts that aim to protect these species in their natural habitats. One of the challenges that zoos face occurs when animals in their collections are not visible to the public, thus causing visitors to have less interest in them. Nocturnal animals can be particularly difficult to garner attention for as their natural sleep cycles do not coincide with typical hours that zoos are open to the public. This was the case for the brush-tailed bettongs (*Bettongia penicillata*) at Smithsonian's National Zoo's Small Mammal House. The objective of this project was to increase the amount of time the building's two bettongs spent visible to the public by reversing their exhibit's light cycle with the hope that their sleep cycle would follow suit.

Brush-tailed bettongs are small marsupials that once occurred in abundance across much of Australia, but human-induced habitat destruction, predation, and resource competition have led to dramatic declines in wild populations. Because of this, the species is currently listed as critically endangered (Wayne et al., 2008). The bettong exhibit within the Small Mammal House is an extremely unique chance for visitors to observe this species while learning about how human action can drastically alter population success. However, guests would often peer into the exhibit, search for the animals for a few moments, and then move along to the next exhibit without noticing the bettongs sleeping in their nests or without pausing to read any information about this rare species.

Prior to the commencement of this project, the bettong exhibit had been placed on a reversed light cycle. This is a method that is used to increase visibility of nocturnal species in zoological settings in which the lighting in an exhibit is altered so that night-level light is simulated during the day and day-level light is simulated at night. If successful, this causes the circadian rhythms of the animals within the exhibit to sync with the new lighting schedule. Nocturnal animals will thus be active during daytime hours when they would typically be asleep in the wild. Although the bettongs' exhibit had been under a reversed light cycle for several months, they had not synced with the new lighting schedule and remained asleep during the day.

The exhibit's original reversed light cycle consisted of night-level lighting between the hours of 0700 and 1900 and day-level lighting between the hours of 1900 and 0700. When this schedule was implemented it was done so that the twelve-hour change from a standard light cycle occurred instantaneously. The proposal for this project involved placing the exhibit back on a standard light cycle to coordinate with the sleeping schedule of the bettongs and then gradually shifting to a reversed light cycle over the course of several weeks. The plan was also to increase the contrast between day-level light and night-level light within the exhibit. It was hypothesized that incremental changes along with stronger environmental cues would facilitate the reversal of the bettongs' sleep cycle and would lead to increased activity during public hours.

## Methods

To gather baseline data, observations were recorded seven times a day for a period of three days. Once the average baseline activity budget for the bettongs had been calculated, the exhibit's lighting hardware was altered. This involved adding one white light to the previous two in order to increase brightness during the daytime condition, removing one of two red lights to decrease brightness during the nighttime condition, and eliminating a white light that had been turning on with the red lights due to a timer discrepancy (see Image 1 and Image 2 for a visual comparison between the daytime and nighttime conditions). The exhibit setup also included a black tarp over the ceiling mesh that blocked out light from overhead skylights. The red and white light bulbs were suspended above the exhibit with metal chimneys that rested on top of the ceiling mesh and the light from the bulbs was directed into the exhibit through holes cut into the tarp (Image 3).

With all of the hardware in place, the next phase of the project was to adjust the lighting schedule. For the first step of this process, the exhibit was returned to a standard light cycle that coordinated with the hours the bettongs spent asleep. This meant that the daytime condition occurred between the hours of 0600 and 1800 and the nighttime condition occurred between the hours of 1800 and 0600. This schedule was in place for one week, after which observations were made and the timers for all lights were shifted forward by ninety minutes to a 0730, 1930 hrs. cycle. Each subsequent week the timers were again moved forward by ninety minutes and observations were made at the conclusion of each period. After ten weeks the light cycle was fully reversed with the nighttime condition occurring between the hours of 0630 and 1830 and the daytime condition occurring between the hours of 1830 and 0630 (see Table 1 for the complete lighting schedule).

**Image 1:** The exhibit as it appears during the daytime condition. One of the three white lights is hidden from view by the frame of the exhibit glass. *Photo courtesy of Clyde Nishimura.*

**Image 2:** The exhibit as it appears during the nighttime condition. The light on the informational signs to the right of the exhibit had previously been casting some illumination onto one of the bettongs' nests. *Photo courtesy of Clyde Nishimura.*

**Image 3:** Above the bettongs' exhibit black tarp covers the ceiling mesh to block outside light. The red and white light bulbs are suspended above the exhibit in metal chimneys that rest on top of the ceiling mesh, and there are holes cut into the tarp to direct the light from the bulbs into the exhibit. *Photo courtesy of Clyde Nishimura.*

| | Daytime Condition with White Light | Nighttime Condition with Red Light |
|---|---|---|
| **Week 1** | 0600 hrs. to 1800 hrs. | 1800 hrs. to 0600 hrs. |
| **Week 2** | 0730 hrs. to 1930 hrs.<br>Daylight Saving Time ended,<br>shifted to 0630 hrs. to 1830 hrs. | 1930 hrs. to 0730 hrs.<br>Daylight Saving Time ended,<br>shifted to 1830 hrs. to 0630 hrs. |
| **Week 3** | 0800 hrs. to 2000 hrs. | 2000 hrs. to 0800 hrs. |
| **Week 4** | 0930 hrs. to 2130 hrs. | 2130 hrs. to 0930 hrs. |
| **Week 5** | 1100 hrs. to 2300 hrs. | 2300 hrs. to 1100 hrs. |
| **Week 6** | 1230 hrs. to 0030 hrs. | 0030 hrs. to 1230 hrs. |
| **Week 7** | 1400 hrs. to 0200 hrs. | 0200 hrs. to 1400 hrs. |
| **Week 8** | 1530 hrs. to 0330 hrs. | 0330 hrs. to 1530 hrs. |
| **Week 9** | 1700 hrs. to 0500 hrs. | 0500 hrs. to 1700 hrs. |
| **Week 10** | 1830 hrs. to 0630 hrs. | 0630 hrs. to 1830 hrs. |

**Table 1.** The complete lighting schedule for the project.

## Results

When the experimental data were analyzed, it was determined that there was a statistically significant difference in the amount of time the bettongs spent resting between baseline average and completed light cycle reversal. Time spent resting decreased from 84% during baseline average to 4% at the conclusion of week 10 when the reversed light cycle was finalized. The maximum time spent resting was 96%, which occurred at week 1, while the minimum time spent resting was 3%, which occurred at week 9 (Figure 1). Additionally, the number of observed behaviors increased over time, from five behaviors during baseline average to twelve behaviors during week 10. The maximum number of observed behaviors was twelve, which occurred at weeks 8 and 10, while the minimum number of observed behaviors was two, which occurred at week 1 (Figure 2).

During the experimental process there were a few challenges that arose. Between weeks 2 and 3 Daylight Saving Time ended and standard clocks moved back one hour. This meant that instead of moving from a 0730, 1930 hrs. cycle during week 2 to a 0900, 2100 hrs. cycle during week 3, the exhibit was instead on a 0800, 2000 hrs. cycle during week 3. With a ninety minute timer increase and a sixty minute standard time decrease, the lighting was only shifted forward by a total of thirty minutes for week 3. Since this was still forward progress, simply in a smaller increment, it was decided that this did not hinder the bettongs' ability to sync with the lighting schedule. Another issue that was discovered was ambient light. At the conclusion of week 5 the observer was standing directly outside the exhibit recording data when the hallway lights were turned on so that the building could open to the public for the day. It had not been noticed previously, but the light that was directed at the bettongs' informational signs was also casting some illumination into the corner of the exhibit where one of the bettongs' two nests was located. This light was shifted slightly to the side so that it did not affect the exhibit as much but still served the purpose of highlighting the signs (Image 2). After this change, week 6 observations demonstrated more significant improvement than previous weeks in terms of how much time the bettongs spent sleeping (Figure 1).

## Conclusion

This successful example of light cycle reversal with brush-tailed bettongs demonstrates the benefits of gradually implementing a reversed light cycle with strong environmental cues when it comes to increasing visibility of nocturnal species in zoos. The method utilized in this study could be attempted with any nocturnal species living in exhibits with controlled lighting. As the project drew to a close, it was highly rewarding to watch visitors excitedly react to seeing the bettongs in their exhibit, hopping around and displaying various other natural behaviors. Although brush-tailed bettongs are only native to Australia, visitors can now take notice of the two in the Small Mammal House, take interest in the species' struggle for survival, and be inspired to take action and participate in local conservation efforts in order to preserve native species.


## Acknowledgments

I would like to thank the staff of the Small Mammal House for their guidance in the development and implementation of this project. Additional thanks are owed to my advisors Kenton Kerns and Ashton Ball for adjusting the light timers each week and for editing this article. I would also like to thank Betsy Herrelko for her invaluable assistance with statistical analyses.


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The two adult female brush-tailed bettongs *(Bettongia penicillata)* at Smithsonian's National Zoo's Small Mammal House.
*Photo courtesy of Clyde Nishimura.*

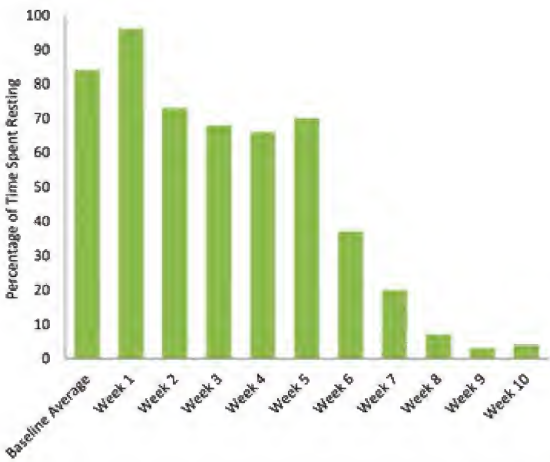



**Figure 1.** The percentage of time the bettongs spent resting each week. After ambient light was altered during week 5, week 6 showed more significant improvement than previous weeks.

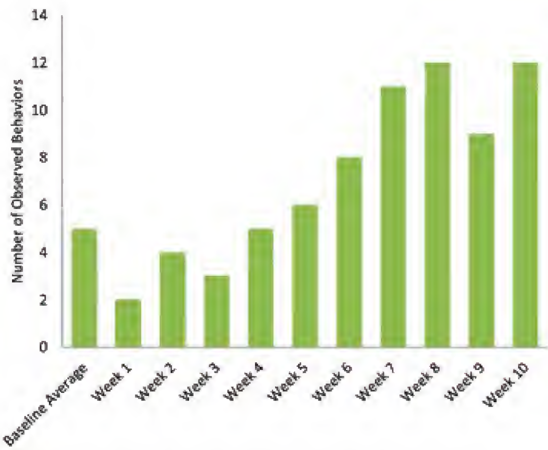



**Figure 2.** The number of behaviors the bettongs displayed each week

Pictured left: An adult female brush-tailed bettong (*Bettongia penicillata*) at Smithsonian's National Zoo's Small Mammal House.
*Photo courtesy of Clyde Nishimura.*

# Behavioral and Hormonal Impacts of Artificial Night Lighting for a Nocturnal Primate, *Perodicticus potto*

Grace Fuller[1,2,A], Mandi Wilder Schook[1,2,B], Mary Ann Raghanti[1,3], Patricia M. Dennis[1,2,4], Christopher W. Kuhar[1,2], Mark A. Willis[2], and Kristen E. Lukas[1,2]

[1]Conservation and Science, Cleveland Metroparks Zoo, Cleveland OH, USA
[2]Department of Biology, Case Western Reserve University, Cleveland OH, USA
[3]Department of Anthropology and School of Biomedical Sciences, Kent State University, Kent OH, USA
[4]Department of Veterinary Preventive Medicine, The Ohio State University, Columbus OH, USA
[A]Present Address: Center for Zoo Animal Welfare, Detroit Zoological Society, Royal Oak MI, USA
[B]Present Address: Disney's Animals, Science and Environment, Walt Disney World, Lake Buena Vista FL, USA

## Abstract

The care of nocturnal species presents special challenges in zoos. Simulated nighttime lighting must be bright enough for visitors to be able to observe animals without overwhelming the animals' sensitive visual systems or negatively impacting their circadian rhythms. In this study, we aimed to determine physiological responses to lighting design for nocturnal primates by measuring behavior and hormone levels in dark phase lighting differing in wavelength and intensity. We compared the behavior of n = 4 pottos (*Perodicticus potto*) when they were living under red and blue dark phase lighting at fixed intensities. We also compared salivary melatonin concentrations within n = 8 pottos as they were moved between red and blue dark phase lighting and at different light intensities. The pottos exhibited higher activity levels when their exhibits were illuminated with red compared to blue light, and these effects were mainly attributable to increased moving and investigative behavior in red light. Melatonin concentrations were significantly higher in red light than blue and decreased significantly with increased intensity for both colors. The results of these investigations suggest that red light may promote greater activity than blue and that circadian rhythmicity is better regulated in red light and at dimmer intensities. These findings can inform future standards for exhibit design.

## Introduction

Nocturnal species make up more than half of the world's land-dwelling vertebrates but often are cryptic and difficult to observe in the wild (Conway, 1969). Zoos provide an opportunity for close encounters with nocturnal animals, but their care in captivity poses unique challenges. Nocturnal species are often housed on reversed light cycles in zoos (Fuller et al., 2013). Artificial lighting is designed to simulate nighttime conditions in exhibits during the day, so nocturnal animals are active when zoo visitors and staff can observe them. Lighting in nocturnal exhibits must be carefully designed to entrain the animal's circadian system to the reversed light cycle, providing enough light for zoo visitors to view nocturnal species without overwhelming the animals' sensitive visual systems or suppressing their activity (Erkert, 1989). This perceptual tug-of-war may have negative effects on the behavior, health, and reproduction of nocturnal species in zoo environments.

Current guidelines for illumination of nocturnal primate exhibits are limited. The husbandry manual for Asian lorisines (Fitch-Snyder and Schulze, 2001) recommends full-spectrum light during the light phase and full-spectrum or red light during the dark phase, but light intensity is not specified for the dark phase. For the aye-aye (*Daubentonia madagascariensis*), the Duke Lemur Center's (DLC) housing guidelines call for red light of less than one lux for dark phase illumination (Williams et al., 2013). A recent survey of husbandry practices for lorises (*Nycticebus* and *Loris* spp.) and pottos (*Perodicticus potto*) in North American facilities showed that red and blue light are being used in roughly equal measure to create nighttime conditions in nocturnal exhibits (Fuller et al., 2013). Despite the occurrence of differed colored night lighting in zoos, there has not been extensive research examining the effects of light color or wavelength on nocturnal primates.

A collection of small-scale studies support the claim that high illuminance levels during simulated nighttime conditions can suppress normal activity levels in nocturnal primates. A reduction in activity with increasing light intensity has been documented in captive galagos (*Galago crassicaudatus*; Randolph, 1971), as well as three slow lorises (*N. coucang*) at the Woodland Park Zoo (Trent et al., 1977). Frederick and Fernandes (1994) simultaneously increased the intensity of simulated day lighting, decreased the intensity of night lighting, and changed night lighting from blue to full-spectrum lighting for two

**Figure 1. Collection of saliva from the female potto Jahzira at Cleveland Metroparks Zoo.** ***Photo by Grace Fuller.***

pottos at Franklin Park Zoo. They found increased activity and behavioral diversity following these changes, but which aspect of the lighting change led to these effects is unclear (Frederick and Fernandes, 1994).

In addition to suppressing activity, nighttime light exposure can cause hormonal changes that have serious health implications. Evidence is mounting that artificial lighting can disrupt internal timekeeping systems, adversely impacting health, reproduction, and behavior in humans and other animals (Navara and Nelson, 2007; Rea et al., 2008). These effects are dramatic enough that the World Health Organization categorizes shift work as a possible carcinogen (Straif et al., 2007). The American Medical Association recommends avoiding light exposure before bedtime—particularly blue-shifted wavelengths from cell phones and other LED screens—because of its negative impacts on circadian rhythmicity (AMA, 2012). Nocturnal primates, which have sensitive visual systems highly adapted for foraging and traveling in darkness, are likely to be particularly susceptible to these effects.

The physiological impacts of nighttime light exposure are largely mediated by hormonal changes. The pineal hormone melatonin plays a critical role in transmitting information about time of day to the circadian system (Arendt, 2005). In both nocturnal and diurnal species, circulating melatonin levels are much higher during the dark phase of the light-dark cycle (Altun and Ugur-Altun, 2007). Exposure to light at night suppresses nocturnal melatonin production in a manner dependent on both light intensity (Zeitzer et al., 2000) and wavelength (Brainard et al., 2008). In humans, peak melatonin suppression occurs by exposure to light in the range of visible blue light (Brainard et al., 1999). Even relatively dim blue light can suppress melatonin production; the threshold for intensity for blue light suppressing melatonin in horses has been measured at three to ten lux (Walsh et al., 2013). The photopigment in the eye that communicates to the circadian system, called melanopsin, is sensitive to these shorter wavelengths, which explains the dramatic effects of blue light on the body (Bailes and Lucas, 2010). As demonstrated in both humans and rodent models, the damaging effects of light-induced melatonin suppression include infertility, metabolic syndrome, and cancer (Navara and Nelson, 2007). Because of their sensitive eyes, nocturnal animals are much more susceptible to light-induced melatonin suppression than diurnal species (Reiter, 1991).

In this paper, we report on a set of experiments examining the impacts of simulated nighttime light color and intensity on the behavior and hormone levels of pottos living under reversed light cycles in three zoos. We collected saliva samples from pottos living in different light colors and intensities to measure the hormone melatonin as a biomarker for the physiological effects of light composition (Corbalan-Tutau et al., 2012; Mirick and Davis, 2008). We also collected observational data on potto activity in a subset of these individuals after experimentally changing their nighttime lighting between blue and red. We hypothesized that pottos living in red-hued nighttime conditions would have higher levels of activity and of salivary melatonin, and that melatonin levels would be lower in animals living in higher nighttime light intensities. The results of these experiments provide empirical data on the impact of lighting design for the welfare of nocturnal primates in zoos and could inform future standards for exhibit design.

## Materials And Methods

*Subjects and Housing*

The subjects for these experiments consisted of 5.3 (#male: #female) pottos (*Perodicticus potto*): 1.1 pair at Cleveland Metroparks Zoo (CMZ) in Cleveland, OH; 3.2 pottos at Cincinnati

**Table 1.** Potto subjects and housing conditions for the multi-zoo study.

CMZ = Cleveland Metroparks Zoo, CZBG = Cincinnati Zoo and Botanical Garden, FPZ = Franklin Park Zoo.
Saliva samples were collected from all subjects for hormone analysis, and behavioral data were also collected on the subset of individuals marked *.
C1 = condition one, C2 = condition two, C3 = condition three.

| House Name (Regional Studbook) | Sex | Age (y) | General Study Design C1:C2:C3 (R=red, B=blue) | Zoo Enclosure | Exhibit Dimensions (LxWxH m) | Lighting Regimen (L:D hrs) | Red Dark Phase Intensity (lux) | Blue Dark Phase Intensity (lux) |
|---|---|---|---|---|---|---|---|---|
| Jahzira* (1311) | F | 6 | R:B:R | CMZ Potto Exhibit | 2.9 x 4.9 x 4.3 | 12:12 | 0.34 | 0.65 |
| Ringo* (1236) | M | 19 | R:B:R | | | | | |
| Tiombe* (1266) | F | 11 | B:R:B | CZBG Potto Exhibit | 0.91 x 0.91 x 1.22 | approx. 14:10 (D phase varies from 9 to 14 hrs) | 38.7 | 37.6 |
| Amare* (1312) | M | 5 | B:R:B | CZBG Potto/ Bamboo Lemur Exhibit | 0.91 x 0.91 x 1.83 | approx. 14:10 (D phase varies from 9 to 14 hrs) | 16.12 | 15.3 |
| Gabriel (1248) | M | 16 | R:B:R | CZBG Nocturnal Building Holding | 0.91 x 0.91 x 1.83 | 12:12 | 1.32 | 1.03 |
| Lucy (0085) | F | 12 | B:R:B | CZBG Nocturnal Building Exhibit | 2.9 x 1.8 x 2.3 | 12:12 | 1.32 | 1.03 for C1; 37.6 for C3 |
| Jabari (1273) | M | 11 | B:R: brighter B | | | | | |
| Rendille (1215) | M | 24 | R:B: brighter B | FPZ Exhibit | 1.83 x 1.22 x 1.52 | 12:12 | 5.2 | 5.4 for C2; 36.9 for C3 |

Zoo and Botanical Garden (CZBG) in Cincinnati, OH; and 1.0 potto at Franklin Park Zoo (FPZ) in Boston, MA (Table 1). All subjects participated in saliva collection, and behavioral data were collected on the two pottos at CMZ and two at CZBG (Table 1). The pottos at CMZ were housed together in an exhibit in the nocturnal wing of an indoor primate facility, which they shared with a greater galago (*Otolemur garnettii*) during the last study phase only. At CZBG, Amare and Tiombe were housed in separate exhibits also located in a nocturnal section of an indoor primate facility. Amare shared his exhibit with a bamboo lemur (*Hapalemur griseus*). Jabari was initially housed with Lucy in a nocturnal building at CZBG but moved to share the exhibit with Tiombe during the third study condition. Gabriel was housed solitarily in a holding area in the nocturnal building. Finally, Rendille at FPZ was housed alone in an exhibit located in an alcove of a greenhouse structure predominantly housing diurnal species.

Lighting conditions for each enclosure are detailed in Table 1. Baseline lighting for Rendille (FPZ), Gabriel (CZBG), and the pottos at CMZ was red, while the remaining pottos at CZBG were housed under blue light at baseline. Light colors were shifted to red or blue for dark phase illumination using gel filters (Rosco Laboratories Inc., 52 Harbor View, Stamford, CT 06902, USA, www.rosco.com: red #2001 and blue #4290, 4260, and 4230) over fluorescent (CMZ) or halogen (FPZ) fixtures, or using blue or red plastic tubes at CZBG. Light phase illumination consisted of white or full-spectrum light for all subjects. Light intensities in the exhibits were measured using a SPER Scientific light meter (#840020, 8281 E. Evans Rd., Suite 103, Scottsdale AZ 85260, USA, www.sperdirect.com).

*Study Design and Data Collection*

This study was conducted to compare red and blue light using an AB(A) experimental design at three institutions, with some additional data on light intensity collected opportunistically. Data were collected at CMZ from October, 2012 to February, 2013, at CZBG from February to May, 2013, and May to July, 2013 at FPZ. The basic study design consisted of three conditions representing different dark phase light colors while all other aspects of lighting design were kept constant; however, there were a few exceptions (Table 1). The pottos at CMZ and Amare and Tiombe at CZBG remained in their home exhibits while dark phase lights were altered to create three conditions: (1) baseline light, (2) experimental color change, and (3) a second baseline. At CZBG, instead of changing exhibit lights for the experimental condition, Jabari and Lucy moved from their blue exhibit to the red nocturnal holding area, and Gabriel was moved from the red holding to the blue exhibit. Instead of returning to his exhibit after this study phase, Jabari moved into the brighter blue exhibit with Tiombe. To replicate this change in intensity, Rendille at FPZ stayed in his home exhibit, but after the experimental blue condition his lights were changed to a brighter blue for the third condition rather than back to the baseline color. In summary, the only animals that moved from one exhibit to another were subjects utilized for saliva collection only; behavioral data were only collected on pottos that remained in their home exhibits for the duration of the study, in order to ensure that exhibit moves did not bias behavioral results.

For hormone analysis, the pottos were conditioned for voluntary collection of saliva samples before the onset of the experiments. Saliva samples were collected using a pole apparatus similar to that described by Lutz et al. (2000) (Figure 1). The pole consisted of a 1.5 m fixed length of PVC (1.27 cm diameter) with a collection medium attached at one end. Saliva was collected by enticing the pottos to chew on children's swabs (Salimetrics, LLC, 101 Innovation Boulevard, Suite 302, State

College, PA 16803, USA, www.salimetrics.com) flavored by dipping the swab in a 1:3.5 dilution of honey in water and drying them for 48 hours. To extract saliva from swabs, swabs were centrifuged in collection vials for 15 minutes at 3500 rpm. For analysis of dark mid-phase melatonin, samples were collected six hours after the onset of the dark phase from each subject. Total samples collected in red: blue: brighter blue were: 14.10.0 Jahzira, 14.8.0 Ringo, 10.20.0 Tiombe, 1:3:0 Amare, 17.7.0 Gabriel, 8.13.0 Lucy, 10:10:10 Jabari, and 15.15.14 Rendille.

Behavioral data were collected on Jahzira, Ringo, Amare, and Tiombe using continuous sampling during ten-minute observation sessions for a total of 20 hours of data in each study condition for each potto. Behaviors were recorded using The Observer 5.0 software (Noldus Information Technology BV, Nieuwe Kanaal 5, 6709 PA Wageningen, Netherlands, www.noldus.com) and a simple ethogram consisting of social behavior, moving, feeding, self-grooming, investigating, resting, or not visible. Observations at CMZ were balanced across the entire dark phase, while observations at CZBG were only conducted during a portion of the dark phase, from 0900 to 1800 h.

### Hormone and Data Analysis

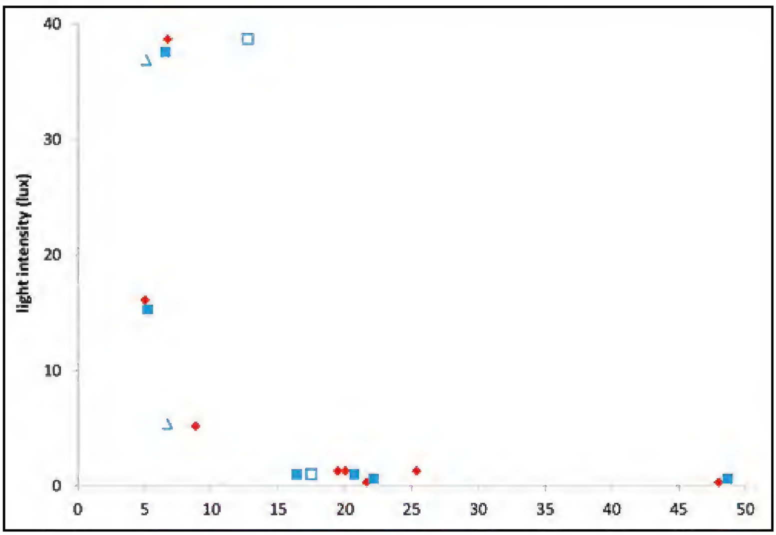
Salivary melatonin concentrations were measured in un-extracted saliva diluted 1:10 using a commercial enzyme immunoassay (melatonin EIA, IBL International Corp., 288 Wildcat Road, Toronto, Ontario M3J 2N5, Canada, www.ibl-international.com) in the endocrinology lab at CMZ. The assay was chemically validated for pottos by establishing parallelism of a serially diluted pooled sample to the standard curve ($t = -1.111$, $p = 0.303$) and by analyzing recovery of hormone in pooled potto saliva spiked with controls. Recoveries for saliva spiked with 2.4 pg/ml of melatonin averaged 68%, while recoveries with 15.0 pg/ml of melatonin averaged 100%. We also tested for interference of the honey flavoring by directly analyzing it in the EIA and found no detectable concentrations of melatonin. We biologically validated the assay by comparing melatonin concentrations in potto saliva collected during the light phase to the dark phase. Mean melatonin concentrations varied significantly with light phase (41.44 $\pm$ 4.02 pg/ml $\pm$ SE for the dark phase (N=16) vs. 20.28 $\pm$ 1.80 for the light phase (n=13), $t_{29} = -5.010$, $p < 0.001$). Inter- and intrassay coefficients of variation were both below 12% for the results presented here.

For comparing melatonin values between red and blue light, values from the brighter blue condition experienced only by Rendille and Jabari were excluded to isolate the effect of color when intensity was held constant. Melatonin concentrations were then log transformed and compared between red and blue light using a generalized linear mixed model with a normal distribution and an identity link function, and subject ID as a random effect. To examine the effect of intensity, correlations between each subject's average salivary melatonin concentrations in each light color (red, blue, or brighter blue) and light intensity were examined within each color using non-parametric Spearman rank correlations.

For behavioral data analysis, the percent of time spent performing each behavior was calculated for each observation. To compare the overall amount of time spent active, all active behaviors (social, move, feed, self-groom, and investigate) were combined. Differences between the

Cleveland Metroparks Zoo Potto exhibit

**Figure 2.** Scatterplot of light intensity compared to mean salivary melatonin concentrations measured in pottos at six hours after dark phase onset. Melatonin concentrations were measured in eight pottos in red (red diamonds) and blue (blue squares) lighting. Open squares represent mean values taken at two different blue light intensities for Jabari, and open triangles indicate the same for Rendille.



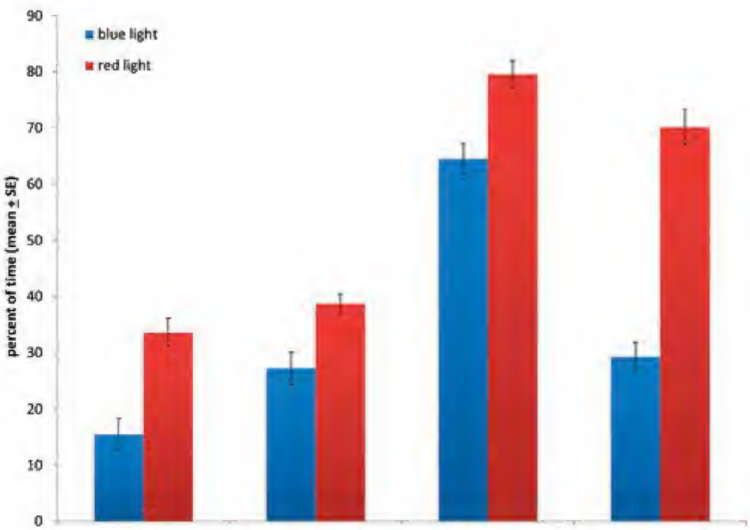



**Figure 3.** The mean ± SE percent of time spent performing all active behaviors grouped together (social, move, feed, self-groom, and investigate) in each of four pottos in red and blue dark phase lighting. Standard error bars are based on number of observations in blue: red = 131: 257 for Jahzira; 159: 414 for Ringo; 225: 121 for Tiombe; and 225: 118 for Amare.

percent of time performing behaviors under red and blue lights were compared using a generalized linear mixed model with a gamma distribution and a log link function, and subject as a random effect. Values were transformed by adding a constant (1) because the gamma distribution only allows values > 0.

## Results

We first compared salivary melatonin concentrations measured in the same subjects under both red and blue light while holding intensity constant. Salivary melatonin concentrations were significantly higher when the pottos were living under red light during the dark phase compared to blue ($F_{1,162} = 4.2$, $p = 0.042$). We then examined relationships between light intensity and melatonin concentrations (Figure 2). Melatonin concentrations in red light decreased significantly with increasing light intensity ($n = 8$, Spearman's $\rho = -0.884$, $p = 0.004$). The same trend was found for blue light, in which lower melatonin concentrations were measured in animals living in higher dark phase light intensities ($n = 10$, Spearman's $\rho = -0.825$, $p = 0.003$).

Behavior data analysis showed that the percent of time spent performing active behaviors was higher when the pottos were living in red light than in blue (Figure 3; $F_{1,1648} = 86.7$, $p < 0.001$).

We then compared rates of specific active behaviors performed by the pottos under red and blue nighttime lights. All active behaviors were more common in red light (Figure 4), but this difference only reached statistical significance for the percent of time spent moving ($F_{1,1636} = 101.0$, $p < 0.001$) and investigating ($F_{1,1648} = 45.0$, $p < 0.001$). Social behavior was not compared due to the differences in housing conditions among subjects and its low rate of occurrence even in socially housed animals.

## Discussion

We conducted a series of experiments at three zoos aimed towards generating empirical data on how to design simulated nighttime lighting for nocturnal primates that best promotes health and activity. Ideally, nocturnal animals have high activity levels and high melatonin levels during their dark phases. Our hypothesis that red dark phase light would be associated with higher activity and circulating concentrations of the timekeeping hormone melatonin compared to blue light was supported, as was the prediction that melatonin levels would decrease with increasing light intensity in exhibits. The potential implications of these findings for the health and welfare of nocturnal primates like pottos require further investigation, but the results do suggest at least that the practice of housing nocturnal primates in blue light should be further scrutinized.

The hormone data presented here provide preliminary evidence that circulating melatonin concentrations in pottos are impacted by the wavelength and intensity of exhibit lighting. Red light seemed to be associated with higher melatonin concentrations, a result we also found comparing red and blue dark phase lighting in an aye-aye at Cleveland Metroparks Zoo (Fuller et al., *in press*). The modest effect we observed here should be tested further under more controlled conditions. At all facilities, the pottos were exposed to uncontrolled light from visitors, keepers, and other sources. None of the facilities in this study consistently used red or dimmed light in keeper areas, and pottos were often exposed to white light as staff entered exhibits for animal care or saliva collection. The inability to control these other sources of light could have impacted the results found here, although we assume the within-subjects study design accounted for this possibility to some degree. Future studies should also explore the impacts of such uncontrolled or incidental light exposure for animals in zoos. In laboratory rats, exposure to light from hallways (as low as 0.2 lux) seeping into animal rooms underneath doors decreased melatonin amplitude and increased tumor growth relative to control subjects housed in true darkness (Dauchy et al., 1997). Thus, it is possible that sources of light outside of nocturnal exhibits may have significant biological impacts on their inhabitants as well.

The correlational data we collected on the impact of light intensity on melatonin levels also appears to demonstrate a physiological effect of exhibit lighting on pottos. Animals in this study living in darker enclosures had consistently higher concentrations of melatonin in their saliva. These correlational data do not account for the possible effect of age, and melatonin levels are known to decline with age in humans (Arendt, 2005). In humans, half of maximal melatonin suppression is achieved by nocturnal exposure to light of 100 lux (Zeitzer et al., 2000), and exposure to ordinary levels of room light before bedtime suppresses melatonin production (Gooley et al., 2010). However, melatonin is suppressed by lower intensities in nocturnal species, and light near one lux can suppress pineal melatonin production in Syrian hamsters (Brainard et al., 1982). Without having a true baseline of melatonin under natural lighting conditions, it is difficult to determine if melatonin production was suppressed at any (or all) of the intensities we measured. However, given the negative impacts of melatonin suppression that are well established in other species, it might be sensible to err on the side of caution and keep exhibits relatively dim.

The behavioral trends we observed comparing red to blue light suggest that blue light suppressed activity in addition to hormone

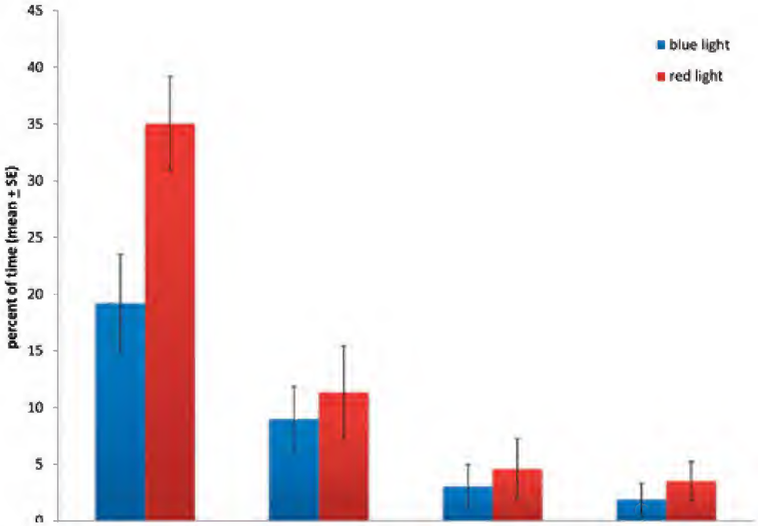



Figure 4. The percent of time (mean ± SE) spent performing specific behaviors in pottos in red and blue dark phase lighting. Standard error bars are based on n = 4 pottos.

levels. Pottos spent significantly less time moving around their exhibits and engaging in investigative behavior when housed under blue light. We also observed a decline in activity levels under blue light in additional subjects at Cleveland Metroparks Zoo, including pygmy slow lorises (*Nycticebus pygmaeus)* and moholi bushbabies (*Galago moholi*) (Fuller et al., *in press*). Locomotor behavior has long been the standard measure of activity in laboratory studies of circadian rhythms (Bartness and Albers, 2000), and exposure to light during the dark phase has been documented to have a masking or suppressive effect on locomotor behavior in a variety of species (Redlin, 2001). In pottos, it appears that blue light more strongly suppressed locomotor behavior than red.

There are several implications of these results for husbandry practices for nocturnal primates in zoos. Erkert (1989) proposes that artificial lighting regimens for nocturnal primates are effective when animals show evidence of stable circadian rhythms without any apparent masking of activity during the dark phase. Because blue light appeared to mask activity in our subjects, it follows that red would be a better choice. However, moonlight is reflected sunlight, and nighttime light is similar in color composition to sunlight with some added longer wavelengths from stellar sources (Melin et al., 2012). Partly for this reason, dim white light is sometimes recommended for exhibiting nocturnal primates (Fitch-Snyder and Schulze, 2001; Walker, 1968). Further investigations could examine the relative impacts of full spectrum light for nighttime exhibits as opposed to light shifted towards blue or red wavelengths. There are also still many other unanswered questions, including the optimal light composition and intensity for artificial light phase illumination, the importance of mimicking twilight rather than abruptly shifting light phases, and the impacts of photoperiod length and seasonal alterations thereof. This research sheds light only on one element of nocturnal lighting design—the spectral composition and intensity of the dark phase. Given the choice between blue and red, we recommend dim red dark phase lighting as best for the welfare of nocturnal primates exhibited in zoos.

## Acknowledgments

The authors would like to thank all the dedicated animal care professionals who made this research possible, including: Laura Amendolagine, Becky Johnson, Andi Kornak, Pam Krentz, Austin Leeds, Albert Lewandowski, Terri Rhyner, Tad Schoffner, Dawn Stone, Heather Mock Strawn, and Andrew Smyser at Cleveland Metroparks Zoo; Patrick Callahan, Mike Dulaney, Ron Evans, Michael Guilfoyle, Valerie Haft, Janet Hutson, Michael Land, Mike Maciariello, Kate MacKinnon, Matt Miller, Terri Roth, Stephanie Schuler, Vicki Ulrich, and Amanda Weisel at Cincinnati Zoo and Botanical Garden; and Jeannine Jackle and Nicole Smith at Franklin Park Zoo. We also wish to thank Helena Fitch-Snyder for her studbook data. Finally, we also wish to thank Mariana Figueiro of the Lighting Research Center, Rensselaer Polytechnic Institute and Patricia Higgins at Case Western Reserve University for their input on study design.

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# Providing Artificial Ultraviolet Light to Callitrichidae at Cheyenne Mountain Zoo

Rick Hester, Lead Animal Keeper
Cheyenne Mountain Zoo, Colorado Springs, Colorado

The taxonomic family Callitrichidae is a family of New World primates (NWP's) that consists of all marmoset and tamarin species as well as Goeldi's monkeys (*Callimico goeldii*). They are native to the forests of Central and South America.

Signs of vitamin $D_3$ deficiency have been seen in many species of captive non-human primates but occur more frequently in NWP's than in Old World primates. This has led many to hypothesize that NWP's have a higher vitamin $D_3$ requirement to remain healthy than other primate species. Access to ultraviolet light (UV) is an important factor in increasing vitamin $D_3$ levels and needs to include adequate levels of UVA, UVB, and heat for proper absorption. At Cheyenne Mountain Zoo we have one outdoor Callitrichidae exhibit that is shared by multiple groups of callitrichids (they take turns throughout the week). They are only able to use this exhibit from May-Sept due to cold temperatures the rest of the year. Our golden lion tamarin (*Leontopithecus rosalia*) group is housed in a different location and has no access to unfiltered sunlight. In late 2012, in an attempt to address some gastrointestinal health issues with our Geoffroy's marmosets (*Callithrix geoffroyi)* and improve the overall husbandry of all our Callitrichidae species, we began providing artificial ultraviolet light sources.

We started with mercury vapor UV bulbs. The bulbs were placed 7.62cm above the ceiling mesh panel of our exhibit and a basking location was hung 15.24cm below the ceiling mesh. The basking location was a 60cm x 60cm hanging wooden bench. In one of our exhibits there is no mesh on the ceiling so we constructed a mesh box to contain the light fixture and to prevent the animals from getting burned. We provided the light for six hours/day, and observed the animals basking several times a day for 5-15 minutes at a time. They would hang off the ceiling mesh (or mesh box) and bask their abdomens as well as lay on the bench in various positions. These behaviors began immediately after activating the lights for the first time. We tested UVB output using a hand-held ultraviolet radiometer UVB

Golden lion tamarins using light fixtures during grooming

meter. It measures UVB output in uW/cm$^2$ (the higher the number, the more UVB output). With the mercury vapor bulbs we had readings of ~100-120 uW/cm$^2$ at the ceiling mesh panel (7.62cm away from the bulb) and of 50-75 uW/cm$^2$ at the bench 22.86cm away from the bulb. We needed to replace the bulb every three months in order to maintain similar levels of UVB output. To give some perspective, we tested the UV levels in our outdoor marmoset exhibit on a clear, sunny day during the summer solstice. This is the time we hypothesized we would see the highest UV output from the sun. This measurement was taken on June, 20, 2012 at the following coordinates: 38° 46.276'N / -104° 51.261 W at an altitude of 2068m we had a reading of 360 uW/cm$^2$. We continued to provide access to mercury vapor UV bulbs for the next couple of years. We did not see any changes in the gastrointestinal symptoms of our marmoset group. We did see an improvement in vitamin $D_3$ levels on bloodwork for some of the animals who had access to the UV light compared to results prior to adding the artificial UV light. However, we were only taking blood opportunistically when animals were immobilized for other purposes so have limited data and in many cases the animals were ill. We were also making dietary adjustments at the same time. Because of this, we cannot show definitively that the UV lights resulted in increased vitamin $D_3$ on blood work.

In late 2014, we became aware of some new technology in artificial UV lighting, "Light Emitting Plasma Lamps" (LEML's). This technology was designed for large aquariums, but some zoos had begun utilizing it for NWP's. We began using these new light fixtures in early 2015. The new lights had to be suspended from a fixture-based bracket, so simple frames to hang them were constructed. We put the LEML's in the same locations where the mercury vapor bulbs had been. The LEML's have a water protective glass shield in front of the bulb and produced the same UVB output as the mercury vapor bulbs. By removing the glass shield, we got readings of > 300 uW/cm$^2$ at the 7.62cm mark (ceiling mesh panel) and 150 uW/cm$^2$ at the basking bench (22.86cm away from the bulb). We are still getting those readings after 18 months of use. We should note that modifying the fixtures in any way may affect warranty agreements. The areas we are using these fixtures get very warm seasonally, and we have run into issues of the power supply overheating which damages the fixtures. We are currently experimenting with small computer fans built into the light frames to try and keep them cool.

We are seeing even higher vitamin $D_3$ levels on the bloodwork of animals that have access to LEML's. We still only have a small amount of data taken opportunistically. Anecdotally, we have also seen a decrease in the frequency of gastrointestinal symptoms of our marmoset group though we have concurrently made dietary changes, providing a confounding variable. After six months of using the LEML's with our golden lion tamarins, we began to notice their coat coloration darkening. Our tamarins do not have any outdoor access, and have historically been very light in color compared to free-ranging tamarins.


Geoffroy's Marmoset
*Photo courtesy of Ashley Arimborgo*

More data is needed, and we will continue to gather information through bloodwork assessment, radiographs (x-rays), dietary modification, and monitoring the overall health of our Callitrichidae species. Because of the improvements we've seen in bloodwork, GI symptoms, and coat appearance so far, we feel strongly that it's important to provide an artificial UV light source for Callitrichidae species that do not have regular, daily access to unfiltered sunlight. For our zoo, the LEML's have been the most effective source of artificial UV light so far.

# Light is for Babies too: Managing the UV-B exposure on hand-reared birds

González, P.M[1]., Gattinoni, V[1]., Suares, A[2].

1. Incubation and Hand-rearing Centre Keeper, Fundación Temaikèn, Buenos Aires, Argentina. Contact: pmgonzalez@temaiken.org.ar, vgattinoni@temaiken.org.ar

2. Incubation and Hand-rearing Centre Supervisor, Fundación Temaikèn, Buenos Aires, Argentina. Contact: asuares@temaiken.org.ar,

## Introduction

The primary action of Vitamin - D3 (cholecalciferol) is to promote gut absorption of calcium by stimulating formation of calcium-binding protein within the intestinal epithelial cells. Vitamin D-3 is formed in the skin when a cholesterol precursor is exposed to ultraviolet light, particularly to UVB radiation. Calcium plays a central role in a wide range of essential functions like normal neuromuscular function, cardiac contraction, blood clotting, membrane permeability and activation of enzymes as well as for serving as the structural foundation of the skeleton (Wissman, 2006). A long-term dietary deficiency of calcium or of a negative dietary calcium-to-phosphorus (Ca: P) ratio generally leads to metabolic bone disease (MBD) (Zotti, 2004).

Giving animals access to direct, unfiltered, and unobstructed sunlight with accessible shade and water is the best way to ensure the animal is receiving the UVB exposure necessary to produce vitamin D3 (Schmitdt, 2010). Unfortunately, sunlight received through glass will contain little, if any, UVB radiation because UVB rays are absorbed by glass and most acrylics (Ullrey and Bernard, 1999).

Exposing animals to direct sunlight is not always possible, especially when working with neonates. At our facility we don't have the elements to measure UV radiation, or Vitamin D conversion, so we have developed our UV-B exposure practices for hand-reared birds based on years of experience and chicks reared. Here we report our practices with several species to provide neonates exposure to UVB radiation while they are being hand-reared.

## Materials and methods

Hand-rearing Facility

Fundación Temaikèn has an Incubation and Hand-rearing centre (CIyR for its initials in Spanish) located in the Rehabilitation Centre, three kilometers away from the Biopark. The CIyR is divided into different rooms according to the stage of development of the chicks reared there:

- Cooling area
- Incubation room
- Altricial chicks room
- Precocial chicks room
- Weaning-area

For the purpose of this experience, we will describe with more details the last three.

***Altricial chicks' room***

This room consists of two marble countertops facing each other with a corridor in the middle (Photo 1). One marble countertop is exclusively

Photo 1: Altricial chicks room

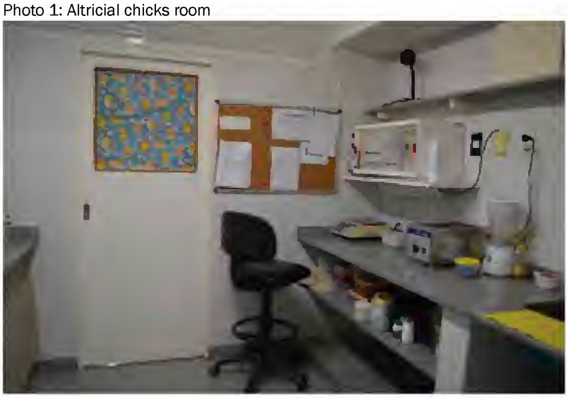

Photo 2: UV fluorescent lamp in altricial chicks room

used as a feeding area, and it has a scale, a thermostatic bath, and a washing sink. A F30W Sylvania Reptistar® UV-B fluorescent tube is located 33 cm over the feeding area.

This room also is provided with three neonatal care units. Altricial chicks (psittacines, toucans, ibises, spoonbills, egrets, hornbills, etc.) are housed here until they are able to tolerate room temperature. The room temperature is maintained at 28° C – 30°C by the use of air conditioners year-round.

***Precocial chicks' room***
This room has four plastic Gaylord containers and three neonatal care units (Photo 2). Each container is provided with a heat lamp, and one F30W Sylvania Reptistar® UV-B fluorescent tube located 60 cm over the container floor. When chicks are located in these containers, a thick mattress of substrate is added, so the distance between the bird and the lamp is decreased. Tubes are turned on early in the morning (0700 h) and turned off when the last keeper leaves the ClyR (1800 h). As mentioned before, we don't have the elements that would allow us to measure the UV-B irradiance level through time, so tubes are replaced once a year.

In this room, precocial chicks (cracids, ducklings, geese, swans, cranes, and ratites) are housed. Also, we can use this room for older altricial chicks that can tolerate room temperature which is maintained at 25° C.

***Weaning-area***
This is the largest room of the ClyR, and the one with the coolest temperature; chicks are kept here in a range from 22 °C to 24°C (Photo 3). Ten pens measuring 170 x 125 x 111 cm high are located in front of a huge window. At the moment we don't have UV-B tubes in nine of these pens since we couldn't solve the risk of birds interacting with the lamp by putting the lamp inside the pen, or leaving it over the roof knowing that the distance is too much for the radiation to have an effect on the birds. We use one UV-B fluorescent tube on a pen where baby black-bellied sliders (*Trachemys dorbigni*) are housed. In this case, putting the lamp inside the exhibit doesn't represent a security issue.

Both altricial and precocial birds can be housed in this room and it represents the last indoor exhibit before moving to a larger outdoor aviary.

## UV-B exposure management

***Cracids, ducklings, geese, swans, tinamous***
These species are housed in the precocial room once they have dried inside in hatcher, so they are exposed to the UV fluorescent tube hours after birth. Most of them spend several days in this room before being moved to the weaning room. As mentioned before, we don't have UV-B light in this room at the moment, but we open the windows leaving a mosquito net in order to provide at least some radiation. We have never had cases of MBO within this group of birds.

***Toucans, pigeons, psittacines***
These species are born without feathers (toucan, pigeons) or with a vestigial down (psittacines). This makes them very susceptible to chilling. Handling time outside the Neonatal care unit should be limited to feeding sessions in order to avoid temperature changes that may be deleterious for the chicks' health (Photo 4). In this case, UV-B exposure is limited to three or five minutes under the fluorescent tube after the chicks have been fed. Once the chicks are moved into the Precocial Room, they are exposed to the fluorescent tubes located on the containers. Finally, they are moved into the weaning room, where we do the same procedure of opening the windows leaving a mosquito net. Also, like the previous group we have never had cases of MBD under this light exposure regimen.

***Ibises, spoonbills and egrets***
In 2011, we hand-reared for the first time three Black-faced Ibis. We followed the same UV-B light exposure that we reported for toucans and psittacines. By the age of 30-days-old, we noted that one of the chicks wasn't able to stand up or move. Vets were consulted and the chick was taken to the hospital for an X-ray examination. Overall deviation of bone, cortical bone thinning and weak and multiple fractures in different bones (tibiotarsus, tarsometatarsus, ulna and radius) were detected. The chick was diagnosed with metabolic bone disease.

Although they didn't show any behavioral signs of disease, the other two chicks were taken to the hospital for Rx. Both of them showed MBD consequences such as deformed bone structure, deformation of the axis, microfractures in several bones, and lumbar lordosis (synsacrum) (Photo 5 and 6).

This experience made us realize that the feeding-session UV-B exposure time was not enough. Unlike parrots and toucans, ibises, spoonbills and egrets are born with a thick down and can cope with temperature changes better than others. This seems logical if you think of the kind

Photo 3: Precocial room

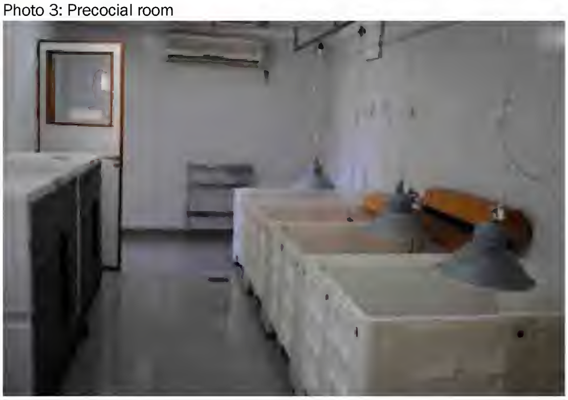

Photo 4: Weaning area

Photo 5: Toco Toucan chick during exposing session

of nest they build: all of the last species build exposed nests on trees or marshy vegetation. We start with three to four 10-minute exposure sessions under the UV-B light in the altricial room (Photo 7). As soon as birds become more active and are able to be at room temperature (20-days-old on average) we move them to the precocial room, where they have 11 hours of UV-B exposure. If the weather allows it, we add one or two 15 minute sessions next to the window with the mosquito net or take them outside under the shade of a tree under keeper supervision.

***Southern ground hornbill (Bucorvus leadbeateri)***

Southern ground hornbill chicks are born without feathers and like psittacines and toucans, they are very sensitive to chilling during the first days of life. During this period, UV-B exposure is provided by feeding under the UV-B light and four 5-minute sessions under the same light in the altricial chicks' room. Once their feather quills start to open, they are moved into the precocial room where they are exposed to 11 hours of UV-B light in the containers. Also, we add at least one 15-minute session of exposure to sunlight through a mosquito net by a window if weather allows it; chicks are taken to an outdoor exhibit for sunbathing sessions. In both cases, a keeper is present at every moment to monitor the chick behavior and the risk of stress and/or overheating.

Photo 6: Black-faced Ibis with MBD Rx 1

***Ostrich (Struthio camelus)***

Last season (2015), we hand-reared for the first time this species. Due to the space required for exercising and the rapid weight gain and growth rates, we assumed that this species would have higher UV-B requirements than any we have previously reared. We decided to keep the chicks in the precocial room only until they were able to stand (3-days-old) and then moved them into an outdoor exhibit. We reared four healthy young birds, and none of the showed MBD signs so far under this regimen (Photo 8).

## Conclusions

As an opportunity for improvement, the use of UV-B fluorescent lights is going to be implemented in the weaning area next breading season. By adding perches inside the exhibits we hope to reduce the distance to the lamps that will be located on the roof of the exhibits.

When a bird is being hand-reared, the conditions required by the chick to meet its basic needs must be provided by the keepers. Except for Ostriches, hand-reared species spend several days indoors before being able to be exposed to direct sunlight. The use of UV-B fluorescent lamps seems to help in the prevention of calcium deficiency-related diseases and the normal growth of the chicks. This proves to be particularly useful for those species prone to chilling, where lighting sessions can take place during the chicks' routine handling (i.e. feeding sessions). Exposure sessions can take place in the same room if temperature is regulated providing the chicks with more time of irradiance. For some species, exposure to direct sunlight during development is essential and they require sunbathing sessions in which a keeper must be monitoring the chick.

Though the information reported here is anecdotal and a recompilation of our experiences, we hope to encourage the consideration of UV-B irradiance during any hand-rearing protocol. It's important to consider the species nesting habits, chicks' morphology and temperature tolerance to develop a UV exposure protocol.

## Products mentioned in the text

Sylvania Reptistar® UV-B fluorescent tube manufactured by SYLVANIA. 200 Ballardvale Street, Wilmington, MA 01887. https://www.sylvania.com

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Photo 6: Black-faced Ibis with MBD Rx front

Photo 7: Black-faced Ibis with MBD Rx side

Photo 9: Ostrich chicks in outdoor exhibit

Photo 7: Black-faced Ibis with MBD Rx 2

Photo 8: Scarlet Ibis during UV session


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# AAZK Professional Development Committee
# First Call for Papers and Posters

**The 44th Annual AAZK National Conference**
**Washington, DC August 27-31, 2017.**

**Conference Theme:** "Keepers United in Saving Species"
Hosted by National Capital AAZK and the Smithsonian's National Zoo

## First Call for Papers and Posters

The AAZK Professional Development Committee is pleased to announce the first call for papers and posters for the 2017 National AAZK Conference hosted by National Capital AAZK. The Host Chapter has chosen the theme "Keepers United in Saving Species", which will highlight how zoo and aquarium professionals work together in protecting wildlife through various conservation efforts.

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- Go to the 2017 conference website http://www.ncaazk.org/2017_conference/papers_posters_workshops/
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- Fill out completely and submit to pdc@aazk.org no later than May 1st

**NOTE:** If you do not use the new application, your abstract will not be reviewed.

## Papers

Papers should focus on the conference theme including innovative approaches and best practices in the areas of husbandry, animal welfare, conservation, education, enrichment and training.

Authors will be allowed 15 minutes for a presentation with five minutes of Q & A immediately following.

## Posters

Posters will be on display throughout the conference with a scheduled Q & A session with the author; time to be determined. Posters will be judged by members of AAZK PDC on criteria such as adherence to the conference theme, innovation, and poster layout and organization. Certificates will be awarded to winning posters at the designated Poster Session.

Middle chick with tape applied by vet staff to help stabilize the leg bones. ***Photo courtesy of Sydney Oliveira, Bird Keeper***

# Use of UV-B Light Therapy in the Treatment of Hypovitaminosis D in Red-legged Seriema

KC Donaldson, Bird Keeper

Saint Louis Zoo, St. Louis, MO

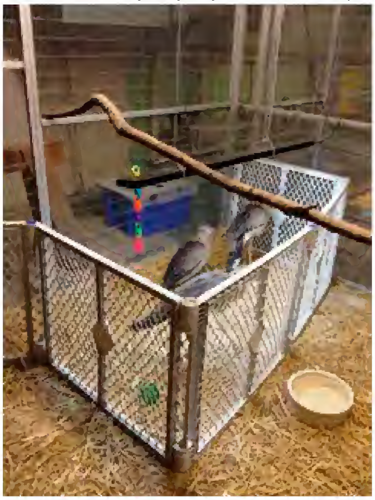
Radiographs showing abnormal bone development. *Photo courtesy of STL Zoo vet staff*

A partition was put in place to ensure the chicks received the correct amount of UV-B exposure. *Photo courtesy of Sydney Oliveira, Bird Keeper*

In October of 2014 the Saint Louis Zoo hatched three Red-legged Seriema (*Cariama cristata)* chicks. Due to cold temperatures and a late lay date, the eggs were pulled from the parents and the chicks were hand-reared in an off-exhibit area. As in any long-legged bird, musculoskeletal problems are common in this species and early detection can improve chances for a successful treatment (Hallager, 2013). The chicks appeared to be developing normally until after approximately six weeks of age where the eldest two chicks were noted as having trouble walking. The birds were diagnosed with Hypovitaminosis D, which included an abnormal curvature of the long bones of the leg. The birds were treated with elastic therapeutic taping, oral Vitamin D3 supplementation and UV-B light therapy twice each day for 20 minutes. UV-B light therapy was a component to the treatment and rehabilitation of Red-legged Seriema chicks with Hypovitaminosis D.

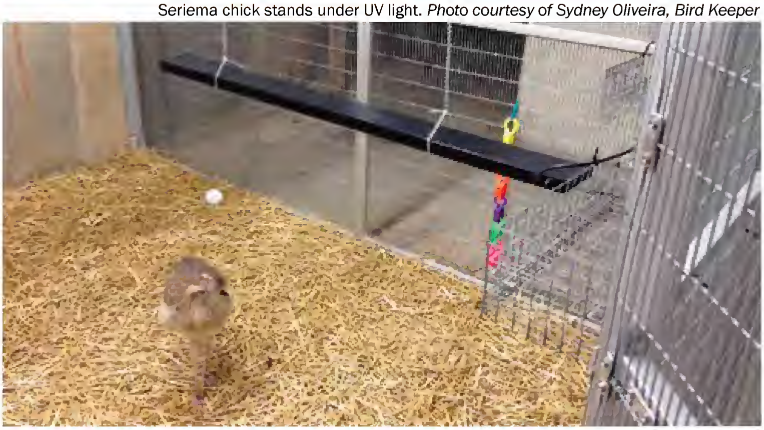
The chicks were raised according to the Saint Louis Zoo's hand-rearing protocol for this species. Chicks started out in a small, plastic (Petiatric) brooder then moved to a large wooden brooder after about two weeks. After one month, the chicks were moved to a small stall that had a concrete floor padded with rubber (Nomad™) mats with straw over the top, and after two months they were moved to a larger stall with the same substrate. Chicks were fed a diet of pinkie mice, waxworms, mealworms, and Toronto Zoo Feline Diet (Milliken Meat Products, LTD) sprinkled with CaC03 and Vionate. As the chicks grew larger, food items such as fuzzy and hopper mice were introduced. Chicks were also exercised daily around indoor, off-exhibit areas for 30

Seriema chicks receiving UV light therapy. *Photo courtesy of Sydney Oliveira, Bird Keeper*



Oldest chick in the sling made by Dr. Matt Kinney, DVM, Dipl ACZM. *Photo courtesty of Sydney Oliveira, Bird Keeper*

Seriema chick stands under UV light. *Photo courtesy of Sydney Oliveira, Bird Keeper*



Red-legged Seriema chicks ages 4-days, 2-days, and 1-day-old. *Photo courtesy of Sydney Oliveira, Bird Keeper*

minutes since exercise is a key component for healthy development in long-legged birds.

Keepers first noted a mild limp in the eldest two chicks at approximately six weeks of age. Over the course of a few weeks the eldest chick's limping gradually progressed to an inability to stand and the chick would primarily ambulate by bearing weight on its hocks. The legs were externally rotated. The second chick also developed a limp, which progressed over time, but the chick was able to stand. The youngest chick of the three chicks had not presented with any clinical signs. Radiographs were taken of the two older chicks, which showed poor bone density and a bilateral deviation of the metatarsal bones just past the hock joints, with the eldest chick having the most significant deviation. Based on the clinical signs, radiographs, and bloodwork results, vet staff began treatment for Hypovitaminosis D.

Due to the varying severity of signs, each chick had a slightly different treatment plan. Vet staff applied elastic therapeutic tape (Kinesio© tape) to the legs of the two older seriema to exert counter-pressure and redirect weight bearing in order to stabilize the legs and straighten the bones. The oldest chick was also placed in a sling for 20-minutes twice a day to allow the legs to extend in an attempt to straighten the bones. The youngest chick had not developed a limp or any bone abnormalities at that time, so no tape was necessary. UV-B light therapy coupled with an oral Vitamin D3 supplement was prescribed for all three chicks to increase their Vitamin D levels in order for their bones to absorb calcium more efficiently. A ReptiSun 10.0 UV-B T5 High Output Linear Lamp was hung three feet off of the ground and a partition was put up around the UV light for 20 minutes twice each day to ensure the chicks got proper exposure. After twenty-four days of treatment the chicks were vastly improved with the most marked success in the eldest chick. The eldest chick was able to stand and walk unassisted by the twenty-seventh day of treatment.

UV-B light therapy was an important component to the successful treatment of the Red-legged Seriema chicks. UV light is a catalyst for a reaction that allows the body to synthesize Vitamin D3. Vitamin D3 then stimulates calcium absorption which is essential for healthy bone development. While most of a bird's Vitamin D3 is thought to come from its diet, birds also naturally synthesize some on the skin via UV-B exposure. A multi-faceted treatment consisting of oral Vitamin D3 supplementation, with UV-B exposure and elastic therapeutic taping in birds with leg deformities was a success and all three chicks grew into healthy adults.

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# Into the Light:
## How low light intensity affects molting in captive thick-billed murres (*Uria lomvia*)

Melissa Vindigni, Keeper 1
North Carolina Zoo
Asheboro, NC

### Introduction

For birds, the change in day-length is the main environmental cue used to coordinate big yearly activities (breeding, migration, and molt) with the changing seasons (Coppack, 2007; Davidson and Menaker, 2003; Dawson, 2007; Helm et al., 2009). Typically those changes are consistent and predictable, but in the Arctic they are not (Gwinner, 2003). With periods of constant light and dark, birds have no day-length changes to synchronize with. So what do they use? Some scientists actually think they use changes in light intensity (Dawson et al., 2001; Gwinner, 2003; Gwinner and Scheuerlein, 1998; Hau, 2001; Vleck and Van Hook, 2002) to keep things on time.

Molting, the process of replacing worn or old feathers, is one of those "big yearly activities". It is a very expensive activity, nutritionally and energetically, since birds are replacing all their feathers (Bridge, 2004). Most temperate birds do this over a period of several months, with some larger birds (like eagles and owls) taking a few years to replace all of their flight feathers. But Arctic birds go big! Puffins and penguins are known to have very intense (sometimes called "catastrophic") molts for either some or all of their feathers. For example, puffins are known to drop all their flight feathers in about two weeks (Bridge, 2004).

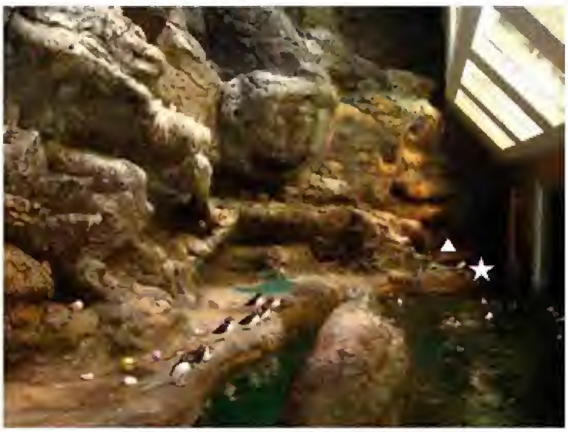
So, in a captive setting how do we set up the best environment that we can for them? A variety of lighting setups are used from 100% sunlight to 100% artificial. While we know we can never match nature perfectly, we still try our best. And though birds can be maintained on a constant light schedule, penguins have been shown to have enhanced reproductive success when housed with varying day length and light intensity (Dawson, 2007; Dawson et al., 2001; Gwinner, 2003; Helm et al., 2009; Henry, 2005).

The Rocky Coast Alcid exhibit at North Carolina Zoo is home to 48 birds of three species including five thick-billed murres (*Uria lomvia*). We strive to provide the best exhibit we can for the birds in our care. To do that, the alcid colony has both artificial and natural lighting and a varying schedule of day-lengths and light intensities. However, a few years ago, while trying to figure out just how much light we had in the exhibit, keepers noticed that several of our thick-billed murres were not molting correctly. Thick-billed murres (TBMs) are the largest extant Alcid species. They go through a full body molt, including contour and flight feathers, in the fall and a partial molt, just contour feathers, in the spring. Because of their distinct winter and summer plumage it was very easy for keepers to determine that they had skipped a molt. Keepers and vet staff had several theories about why they did not molt. The goal of this study was to determine if there was a connection between missed molts and light intensity.

### Methods

The Rocky Coast Alcid exhibit simulates the birds' native Alaskan coastline with large cliffs and a deep (~10') pool. Three sides of the exhibit are dominated by rock walls while front, or viewing window, is mostly glass with a light bay overhanging the front of the pool. Since acquiring our group of murres, keepers have noticed that they tended to hang out on our lower walkway, specifically on the two main skimmers on the far sides of the exhibit. Occasionally, we had a few younger birds climb, but not usually more than 8' or so.

Our lighting system is made up of quartz, metal halide, and sky lights with the goal of providing as much light and spectral quality as possible. At the time of the light study, we also had metal halide and quartz lights in an underwater light bay to provide additional lighting. The lighting schedule is set to mimic that found on St. Lawrence Island, Alaska where many of the birds were originally collected. To maintain this, keepers change all light timers every 10 days and adjust the intensity of quartz lights daily.



Picture shows the bulk of the Seabird Exhibit. The upper light bay overhanging the exhibit's front glass windows is also visible. The front exhibit glass under the upper light bay is where TBM Yl and Or liked to hang out. The "star" shows where Yl like to roost before being displaced to the "triangle".

To figure out just how much light we had in the exhibit, we measured the light intensity with an Extech Instruments Heavy Duty Light Meter ™ set on Tungsten lighting and lux units. The sensor was held at each site for 10 seconds so readings could "stabilize". To try and get a good light intensity profile of the exhibit, we took measurements at pre-determined locations at various heights on the rockwork (up to 3 meters), along the walkway, and above the pool. Measurements were taken once within each ten day period for eight months (Oct – May) to account for seasonal changes in light intensity and taken three times per day (morning - before 10am, midday - between 11:30-2:00, and afternoon - after 2:30pm) to account for daily variation in light intensity. Locations were picked to include what keepers believed to be the brightest and darkest locations in the exhibit and areas where we knew our puffins frequented, as they are our most numerous birds.

Keepers record daily observations after the morning clean and each feed in electronic logbooks. Observations include notes on birds' health, activity, and locations in the exhibit as well as their interactions with enrichment. Since there are four people on our team, we need to have very open (and good) lines of verbal communication. Notes of "odd" behaviors and possible medical issue are left on a dry erase board in our office for others to check on and verify. Because of the murres distinct summer and winter plumages we are able to track the start and end dates for both their spring and fall molt. This helps keepers anticipate when to increase/change the colonies diet to accommodate the extra calories they will need. Also, because we know when to expect them to molt, it was very easy for keepers to realize when molts were delayed or did not occur.

## Results/Discussion

Keepers first noted molting issues for thick-billed murres (TBM) BI and BIYI in 2012. Due to long-term medical treatment, both birds had been housed in an off-exhibit holding area from September 2011 through February 2012. Though they were back on exhibit in time for Spring molt, both birds molted late. Typically Spring molt is finished by March/April. However, BI finished in mid-June and BIYI finished in early July. Keepers were concerned that molting late would affect their Fall molt and by mid-October, though the other three TBM's on exhibit had successfully molted, neither BI nor BIYI had started. By December keepers were positive neither bird would molt. This meant they would maintain their Spring 2012 plumage till the Fall 2013 molt, a year and a half later.

To better track both birds' conditions through this time, keepers communicated specific information verbally after feeds. We informed each other about where the birds were sitting, what they were doing, and their overall physical condition. This information still went into our electronic logbooks, but we wanted to make sure everyone was as up to date as possible. We also coordinated with our vet staff to provide both birds with a daily vitamin supplement (Missing Link Ultimate Avian Formula©) to provide additional nutritional/vitamin support through the long period between molts and hopefully prevent a "hard" molt during the next molting period.

Originally, keepers assumed that BI and BIYI's missed molt was a condition caused by our holding room light system. This space is meant for short-term, not long-term housing. As such, the light system is not as substantial as that in the exhibit with more dark spaces and overall less light intensity. When both birds molted appropriately in Fall 2013 (and every Spring and Fall since), keepers thought the issue had resolved and discussed increasing the lighting in holding should we ever have to house a bird long-term again.

While monitoring BI and BIYI's molt conditions, we also conducted our light intensity study on exhibit. We discovered that the light intensity in our exhibit definitely varied and that what we thought were dark spots and differences in intensities really were. We found differences between seasons and site height from the walkway. But most importantly to our TBM's, we found that our arbitrary "light" and "dark" sites really were different! Light sites had significantly higher light intensity then dark sites year round (ANOVA, all p values $< 0.001$) (Figure 1).

This finding was especially important when in Fall 2013 when two different TBM's (Or and YI) did not molt. Keepers had observed in Summer 2013 that both birds were spending an increased amount of time at the front exhibit glass and rockwork where, as we now knew, there was significantly less light intensity when compared to the rest of the exhibit. After reading several papers on how light intensity can affect molting, keepers started to believe that both birds missed the "lighting cue" that triggers molting. Now that sounded familiar to us. It wasn't exactly like BI and BIYI's situation, but similar enough. Since BI and BIYI returned to the exhibit late in the Spring, the change in intensity from when they returned till the fall may not have been large enough to trigger their molt. These theories were further supported by our 5th TBM Rudy. Rudy was housed completely on exhibit and molted normally in all years. The difference between Rudy, Or, and YI is that Rudy utilizes much of the space of the exhibit getting out of the dark spaces the others typically reside in.

Not molting correctly can have major effects on birds. Alcids are known to go through very quick molts and are rendered flightless because of it (Bridge, 2004; Thompson and Kitaysky, 2004). During this time, their diving ability is also affected and they have to work harder to forage for food (Bridge, 2004). With our TBM's maintaining the same set of feathers for such a long period, keepers were concerned about our TBM's damaging their feathers. Worn feathers may decrease diving ability similarly to when they molt. These feathers also have reduced thermoregulatory and water-proofing capabilities, both of which are vital to cold-weather ocean diving birds (Pokras, 1988).

Luckily three out of the four TBM's maintained their plumage in good condition over the course of the year and a half between molts. However, TBM YI wasn't so lucky. As the time since his last molt increased, he developed bald and thin patches on his chest, rump, and under his wings. He still foraged in the pool, but when he got out or after bathing, he appeared damp when compared to other birds and was often seen shaking while on land. Keepers also noticed that he was preening more often than other birds. Keepers thought all this could be a result of worn/old feathers. We aren't sure of the specifics, but the increased preening could have broken off already weak and old feathers creating bald patches and thinning. This meant he wouldn't have been as insulated as the other birds and wouldn't have been able to thermoregulate normally. If he was trying to stay warm, that could explain why keepers saw him shaking on land. Luckily, he was able to maintain himself enough to stay on exhibit with the rest of the TBM's and with additional food offered, did well till he molted again in Fall 2014.

To further test our theory that these missed molts were caused by lighting, in Summer 2014 keepers started displacing YI from his preferred roosting site on the rockwork next to the pool where it was darkest. For almost a whole year, keepers placed enrichment items in that location. He didn't go far, just a few feet to the left, but more importantly he moved to a brighter location. We also stopped feeding him and Or by the exhibit window and heavily reinforced them for coming away from it and into the light to forage. Since then, YI has molted every Spring and Fall. Keepers have been able to stop putting enrichment on the rockwork by the pool and YI has maintained his roosting site in his new preferred lighter location. An unexpected, but amazing, side effect of all this is that YI now comes up to keepers regularly for hand outs! By rewarding him away from the window we rewarded him closer to us without realizing it and he learned that keepers can be a good thing.

We as keepers are always striving to make the lives of our animals as good as we can. We provide food, enrichment, and training. During these few years, the keepers at Rocky Coast learned a lot about lighting and how even small changes can have big impacts. We learned a few feet left or right can mean molting or not. We learned to be very verbal with each other if we think something is “off”. We learned that everything can be a tool. And that helping one bird can make a big difference with all the others.

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# Discussion of Nocturnal Lighting for Kiwi

Kathy Brader
Smithsonian National Zoological Park
Washington, DC

Anyone who has worked with nocturnal animals on exhibit understands the frustration in finding that ideal lighting, one that makes the animal comfortable and one that the visitor can view the animal. The Brown Kiwi Husbandry Manual states "Nocturnal houses should be bright enough (during the night phase) for visitors to see the kiwi clearly while still being dark enough to encourage the birds to forage in the enclosure" (Fraser and Johnson, 2015). This certainly allows for a broad interpretation and most kiwi houses have quite a range of lighting.

Extensive research into kiwi behavior both in the wild and in captivity is still in its infancy so it is not surprising that we are in the beginning of understanding of the relationship that kiwi have with light. To tackle a complicated subject of eyesight relationship to light is not the intention of this paper, but a slightly better understanding of how the kiwi eye works will help us to make better choices of what kind of light to use (fluorescent, LED, colored, etc.) and the intensity of that light.

Typically nocturnal animals have large eyes to be able to gain enough information of their surroundings to function. As the kiwi is flightless and spends all of their time on the ground, usually in forests or bushy habitats, one would expect it to have very large eyes to improve sight in very dim surroundings. Instead they have very small eyes, and they seem to be very adept at perceiving light intensity. Their relative aperture (light gathering ability) has the same value of 0.95 that is in line of other nocturnal birds and brighter then diurnal birds (Martin et al., 2007). The shape of the kiwi eye is round and not the tubular shape of some nocturnal birds (i.e. owls) and this is more in line of other ratites but the retinal structure is more similar to owls than other ratites (Bowmaker and Martin, 1978; Hall and Ross, 2007; Corfield, 2009). Kiwi have a monocular field of vision as well as a narrow binocular field of vision that totals 125 degrees that they cannot see beyond (Martin et al., 2007). The result is that they can see ahead but cannot see the ground or their bill tip and have a more limited field of vision than other birds both diurnal and nocturnal. Kiwi do not appear to rely on their vision but have a good perception of light intensity (Cunningham, 2007). Kiwi have evolved more complex tactile and olfactory senses more similar to nocturnal mammals than to nocturnal birds. Photoreceptors that kiwi possess indicate that kiwi perceive light intensity and wavelength. They have a thick layer of tightly packed rod cells (photon sensitivity, i.e seeing light at low levels) and few cone cells (this is what allows us to see color) (Martin et al., 2004). We know that the kiwi lost their ability to see color about 35 million years after their ancestors came to New Zealand (Le Duc et al., 2015). Another point to consider in this subject is that with few cone cells they do not seem to have the ability to see in fine detail (Bowmaker and Martin, 1978). Kiwi have a large number of rod cells that are poor perceivers of the red wavelength (Martin et al., 2007). There is a widely-held belief that kiwi do not perceive red light and many facilities use red lighting and red flashlights for kiwi spotting at night.

We know that kiwi have a tremendous sense of smell and with their nares located at the tip of their bill they spend hours foraging with their bills into the soil and leaf litter (Castro et al., 2010; Cunningham, 2007). We know that kiwi are highly territorial and it is thought that they may be releasing chemicals to scent-mark their areas (Castro et al., 2010) which suggests that olfaction may be more important to kiwi than light. Kiwi also have mechanoreceptors (referred to as Herbst corpuscles) contained within their bill tips to receive vibration and pressure information (Cunningham, 2007). Their hearing is excellent and auditory cues seem to make small difference to their foraging but are important to overall behavior of kiwi (Cunningham, 2009). Kiwi are known to be secretive and difficult to locate in the wild; they have highly cautious behavior and seldom come out of their burrows until full dark (McLennan, 1997).

Relationships that animals have with light are closely linked with life cycles and adaptation to the environment; they use it to cue behavior to their daily and seasonal cycles (MacDougall-Shackleton et al., 2009). Light controls many circadian and circannual activities which include food storage, singing, breeding, etc. Increased exposure to light, such as daylight lengthening, will trigger many activities for breeding and increase food consumption (Wang et al., 2002) so we do not know or understand how photoperiods operate in kiwi. In captive situations, inappropriate light intensity can cause stress affecting social communication, such as communication during breeding, and having such a light intensity for the kiwi as a nocturnal animal will probably lead to undesirable stress and/or behavior.

In 2012 a researcher in New Zealand, Roseanne K. Grant (Massey Univ.) undertook research to look at the effect of lighting on captive kiwi. Although more needs to be done on kiwi and light relationships, this is the first in-depth study on improving lighting in nocturnal houses. Ms. Grant conducted three experiments with different kiwi and set ups: a single female (33-years-old, kept in captivity for 29 years at the Kiwi Encounter, Rotorua, New Zealand), eight captive display kiwi, the third was on brooder kiwi chicks (which I will not cover in this article).

The first experiment with the older female which is on a reverse light cycle: her nighttime was illuminated by six 30 watt Phillips PAR38 bulbs colored by blue, yellow, red or green. In her experiment each of these four bulbs were positioned to illuminate a different section of the enclosure; the bulbs were rotated through all four positions for three repetitions, each lasting 12 days. These bulbs were rotated daily to prevent bias coming from environmental variables (i.e. plantings, water source, visitors, etc.). A grid was created to record detailed landmarks and to be able to quickly spot where the kiwi was. The kiwi was released into her enclosure from her nest box at about 8:30am daily, when her


Mt. Bruce, New Zealand. ***Photographer Graeme Simpson***
**(two birds in exhibit: 0.1 white kiwi, Manukura and her mate 1.0 Turua)**

night lights came on, and was shut out of her nest box. Access to her box happened at 5 pm when the day lights came on. Her feeding tube locations were changed daily and live insects were released daily, all of these locations were noted: though her water bowl position remained the same. This enclosure was glassed and fairly soundproof.

The kiwi positions were noted at one-minute intervals during the "night"; light intensity was measured at all the grid squares from several different positions; the light bulbs were changed before the bird was released in the morning and kept in the same position. Observations totaled five hours per day for each day (total of 12 days), and the observations were evenly distributed from 8:30am to 5pm.

Illumination color did not significantly impact the amount of time in each quarter of the enclosure; she did spend more time in one quarter compared to others, although this one quarter had more cover then one other, it had less cover then two others. She also spent much more time in the darker sections of grid squares. The color of the bulbs had no significant impact of her choices, which we now know that kiwi do not see color (this was not known at the time of the research). She also spent more time in the more dimly lit areas but these were structurally open and were located on edges of the enclosure. These areas were illuminated by less than 25 lux of light. She would also spend more time in the dark open areas.

Although as Ms. Grant points out that her conclusions for this research were based on one bird, it appears that no one factor explains the amount of time spent in each area; the light intensity and edge category appeared to have more an of impact on where she spent her time. She spent more time in dark peripheral areas and dark open areas. The fact that kiwi have no color vision but a good perception of light levels helps explain why it's not the color, but brightness, that affects where they spend their time. The results may have been affected by her age and habituation to the enclosure: she was an older animal and spent part of her time napping and minor pacing along the enclosure edges. The enclosure was fairly sound proof but there was noise from visitors; however Ms. Grant did not note any effect during the observation period.

The next experiment was based on eight kiwi at three different facilities. Three birds were indoors (behind glass), three were outdoor display birds (behind a fence) and three were at Kiwi Encounter (KE) housed individually, and two were a male and female pair sharing an indoor enclosure (behind glass) at the National Aquarium of New Zealand (NA). It should be explained that the outdoor display kiwi (KE) are lit at night for nocturnal visitors as the park is open until 10pm or 10:30pm nightly. This experiment was to look at illumination intensity. Included were a young male, a young female, three middle–aged males, two middle-aged females and an older female. All indoor kiwi were under light reversal conditions (starting at 8:30am and back to higher lighting at 6pm). Feeding was different, with the KE birds having food placed at the start of the day and insects released most days-while the NA placed food dishes at 10am and 3pm and no insects released while the experiment was in place. The grid was created for all enclosures and the kiwi positons recorded every minute, in addition to food placement and environmental conditions recorded. The lighting at KE was between five and seven 30 watt Phillips PAR38 bulbs, colored blue, yellow, red or green. The NA had six 30watt Radium halogen lamp bulbs. For her data collection, illumination levels and structure or edge categories were compiled to allow her to determine whether the light intensity affected the amount of time that was spent in the different areas of their enclosures.

None of the three variables (illumination intensity, structure or edge categories) were the main factors for the proportion of time spent in different areas but rather each impacted the kiwi. Though all the kiwi appeared to prefer darker areas, more cover and the edges, individual kiwi tastes added to the mix of results. Enough of the data showed

that individual behavior differences played a part of where the kiwi spent their time and activity levels. When the data were combined, most kiwi spent more time on average in areas illuminated by darker light intensity. Three kiwi that had areas lighter than 10 lux spent less than 20% of their time there, a little over 1/3 of these enclosures had areas that were brighter than 10 lux. Nights of full moon produce a lux at a maximum of 2 lux on a clear night (Vasquez, 1994), which means that wild kiwi are only exposed to a maximum light of two lux. It goes to follow that kiwi nocturnal exhibits should be kept below 10 lux (which is still brighter by 8 lux than a full moon).

Ancient predators of kiwi were most often avian, including the Haast eagle (*Harpagornis moorei*), the goshawk (*Accipiter fasciatus*) and Whekau owl (*Sceloglaux albifacies*) (Holdaway, 1998), all of which had powerful eyesight and were able to see terrain regardless of the amount of light. This suggests that kiwi might have more of an instinct to use cover as a way to avoid these predators. We know that kiwi avoidance techniques are innate rather than learned as sub adults reared in captivity are as likely to survive until the age of first breeding as sub adults raise in the wild that have survived infancy (Colbourne et al., 2005). Ms. Grant's results suggested that kiwi may have a preference towards more structurally complex areas, as all the kiwi spent more time in these areas than in other areas when the data were combined and analyzed, although with some individual preferences. It was noted that kiwi spent more time under ferns, tussock and flaxes which reflects what Taborsky and Taborsky (1995) observed in the wild, where they found kiwi spent more time in areas of marsh, seral and low laying vegetation.

More time on average was spent on the edge of the enclosure; the grid squares that had more than 50% of time spent in them were located on the periphery. Five of the eight kiwi spent more time on the edge of their enclosure. Since we know that kiwi are very tactile creatures, it may be that they use the walls of their enclosure for cues. They have a highly developed sense of vibration they use to sense their surroundings, by probing with their bill (Cunningham, 2007).

Other environmental factors may have affected the results. For instance, some kiwi were housed next to each other and due to the fact kiwi tend to be highly territorial they may have spent more time along the sides of their enclosures. Ms. Grant offers some suggestions to move forward with. Since the color of the lights does not affect the kiwi but the intensity of it does, keeping the intensity at 10 lux and below would create a more comfortable setting for kiwi. Creating a long and more narrow enclosure will have higher percentage of an edge where kiwi spend more time and area of about 50% under cover (low laying plants rather than tree types). Since the color of the light does not affect kiwi it might be worth pursuing learning what color lights humans see more clearly in dim settings.

In conclusion, the results of this research does not have one overlaying factor in building the perfect nocturnal house for kiwi, but it certainly adds considerable knowledge on what will help us to build an improved setting for on-exhibit kiwi. Through my personal observations and others', we do know that some kiwi never seem to adjust well to being on exhibit. Adopting some of Ms. Grant's recommendations may improve the overall quality of these kiwi's lives. My recommendation for anyone interested in a more detailed description of this research is to read Ms. Grant's paper: The Effect of Light on the Captive Brown Kiwi *Apteryx mantelli*; Implications for Captive Management.

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# In the Eye of the Beholder:
## How do birds see the light we give them?

Linda Henry, Supervisor of Birds
SeaWorld San Diego
San Diego, CA

### Introduction

Appropriate light and dark conditions may be as essential to living organisms as is air and water. All species, including humans, have evolved with the constant cycles of the sun. To maintain the well-being of animals in human care, light provision and light environments should address the chronobiology, visual perception, and visual-behavioral needs across taxa. The visual experience of animals often differs significantly from that of humans. Therefore, human visual assessments of light environments, e.g., for brightness or color appearance, are sufficient only to judge the human-visitor perspective.

This is especially true for the provision and evaluation of artificial or supplemental light environments for birds. Birds perceive light along a broader range of the electromagnetic (EM) spectrum than humans which makes humans blind to the avian visual perspective. Birds also process visual information differently to meet the challenges of flight and birds are able to perceive light by means other than through their eyes. Together, these and other specialized aspects of the avian visual system make for a complex topic. A further complication is that for most avian taxonomic groups, species-specific information is lacking or incomplete. The scope of this article will therefore be limited to the most general characteristics of bird vision to help illustrate the complicated nature of light provision. It is hoped that bird managers will come away with an increased awareness of how birds perceive light, an understanding of the potential benefits and effects of light from all sources, and provide a starting point for the creation of well-lit and enriched habitats for birds.

### More than meets the eye

Light environments for birds are not only important to the daily activities of flight and foraging, but also intricately connected to how birds send and perceive the visual-behavioral information necessary for appropriate social and reproductive relationships. Birds are highly visually dependent; mate choice, sexual signaling, prey detection and predator avoidance, migration, geographic orientation, egg recognition and chick-rearing are all visually driven.

The Association of Zoos and Aquariums (AZA) recognizes the importance of appropriate light environments for all animals in human care. Section 1.2 of the Animal Care Manual Template recommends: "Identify spectral, intensity, and duration requirements for your species. Specify daily, seasonal, age related (young), or gender related, etc. changes in light intensity/duration delineations if appropriate." The Animal Welfare committee further recommends that a species be "...able to develop and express species-typical relationships, behavior and cognitive abilities..." which for many bird species are visually driven and may be dependent on the light duration, intensity and spectrum available. The challenge is in having sufficient data available for a given species to understand their particular photic needs. Still, the general avian visual system is well-studied and research data are available across sufficient species groups to help inform lighting provision decisions.

Achieving appropriate and enriched lighting environments for birds should begin in the habitat design or modification phase. Habitat

Across the taxonomic spectrum of Aves, lifestyle and habitat influence visual adaptations; birds from open, high light habitats may rely on ultraviolet (UV) vision more than species from low light habitats.

Eye color varies among species and sometimes by sex.

elements such as the presence or absence of windows and their light transmittance values, exhibit "furniture" and structural elements and even aviary directional orientation may all affect light quality. Where artificial light is supplemented, and more importantly the sole source of illumination, light bulb type(s) and location should address both species needs and maintenance access. Light provision is not just a consideration for indoor habitats. Outdoor aviaries under natural light conditions should be assessed for light bleed from extraneous sources such as from pathway lights, lighted graphics, windowed doors, exit signs, street lighting, sky lights or atria, guest areas, etc., because opposing light schedules may serve to confuse light/dark signals. Additionally, aviary covers, such as shade cloth, may affect light spectrum transmittance. All light environments should be designed to provide the best achievable light in source and spectrum, intensity, and photoperiod from the avian biological perspective.

### A Birds' Eye View

The avian visual system is multi-faceted and complex. Across the taxonomic spectrum of Aves, lifestyle and habitat influence visual adaptations. Terrestrial diurnal birds have very different visual systems than do nocturnal and deep-diving birds; and birds from open, high light habitats may rely on ultraviolet (UV) vision more than species from low light habitats.

But birds share some general characteristics. They have the largest eyes in relation to body size and the most variability in eye structure among vertebrates with a large proportion of their brain devoted to visual processing. Absolute eye size varies across species as does the eye shape which can be globular, tubular or flat. Lens shape also varies, a characteristic not well understood, and the lens can be muscularly altered to refocus light on the retina, e.g., in penguins when transitioning from air to water. The retina in birds is largely avascular. The relative absence of blood vessels prevents shadows and scattering of light giving birds a sharper focus. Birds also have partial voluntary control over the size of the pupil with some variation in pupil shapes. But the most interesting aspects of avian vision, and the most relevant to light provision, are associated with color vision, motion detection, time-keeping and ultimately how artificial light sources may affect visual-temporal and visual-behavioral perception.

### True Colors

Most birds are diurnal and the predominance of information available about color vision in birds is associated with these species; less is known about color vision for birds adapted to dim light environments. In general, birds have the best color vision system among animals but not all aspects of their visual anatomy are well understood. Like the human retina, the avian retina consists of rods and cones, but birds also have an additional set of photoreceptors called double cones. The double cones, absent in humans, are the most numerous type of cone found in the avian retina, particularly in diurnal birds. Unfortunately, double cone function is still unclear but current research suggests that this cone type may be involved in non-color vision related to illuminance and motion detection. Rods are also part of non-color vision, and are more sensitive to light than single cones, so they are part of low light vision. It is the single cones that are associated with daylight and color vision in both humans and birds. Birds also possess oil droplets in the single cone cells, a feature absent in human cones, which filter the light reaching the retinal photopigments to further narrow spectral sensitivity which may help birds to better discriminate between colors and improve color constancy, which is the ability to discern a color under varying illumination levels (e.g., forest or cloudy to full sun).

With so many profound differences in visual structures between humans and birds, how birds "see" color, and each other, is perhaps one of the most difficult concepts to understand from the human visual perspective. Birds have four types of single cones, versus humans with only three. Birds are therefore considered tetrachromats (perceiving four primary colors) compared to humans' trichromacy (perceiving only three primary colors). This is why many bird species, including all passerines, psittacines, hummingbirds and pigeons, are able to see well into the UV end of the EM spectrum and why most birds (studied so far) perceive light outside the spectral perception of human vision. Each of the four cones has an associated photopigment tuned for a specific range of light capture with peak sensitivities within that range. Avian single cone cells are classified as follows:

1. Longwave sensitive (LWS)—"red"
2. Medium wave sensitive (MWS)—"green"
3. Short wave sensitive 2 (SWS2)—"blue"
4. Short wave sensitive 1 (SWS1 or VS/UVS)—"violet sensitive" or "ultraviolet sensitive".

Birds perceive that fourth color range, which is biased toward either "violet" or "ultraviolet". Therefore, the overall visual range in birds can extend from the near UV at ~320 nanometers (nm) to ~ 700 nm on the EM spectrum; human visual perception ranges from only about 400 nm to 700nm (Figure 1). Even "violet" biased birds see beyond the human visual range.

It is this fourth color dimension that makes the avian visual experience impossible for humans to imagine and why human visual assessments of lighted environments for birds are inadequate and misleading. It is possible that birds see at least twice as many colors as humans do, but this is a simplistic description. For birds, human-assessed white is not "white"; to the avian eye white would not be perceived unless all four photoreceptor channels are stimulated. Human-assessed blue is not "blue" for a bird due to the influence or absence of the fourth primary color. And human-assessed brightness is not bright to a bird without the presence of all four primary color channels. Birds perceive hue, brightness and saturation differently; they can discern between more colors, and colors in general likely appear brighter due to the fourth color


**Figure 1.** A visual approximation of the electromagnetic spectrum showing human visual spectral range which is about 390-700 nm.

input. Brightness levels are relevant to color perception. Brightness levels determine how well birds can see color; parrots may require up to 20 times more light than a human to discern the full complement of colors. Ultimately, light perception is a species-specific neural process such that the sum of the single cones together determines the perceived brightness of light and the cones contrasted with one another determine the perceived color of light.

Humans may never know for certain the visual experience of birds and most especially regarding UV acuity. Scientists have tried many different study methodologies in order to better understand the avian visual perspective including extracting and analyzing visual pigments and oil droplets, electroretinography, microspectrophotometry, gene sequencing and behavioral analyses. In one study, analysis of the SWS1 gene suggested that UV vision is rare in seabirds but may be more common among passerines, ratites, psittacines and Ciconiiformes. Another study assessed feather UV reflectance values representative of several species and found that UV reflectance is relatively widespread among birds. Behavioral studies support a possible signal function of UV ornaments, even, it seems, for some seabirds, e.g., in king penguins. Researchers have suggested that the UV reflectance of feathers represents an honest signal of fitness to prospective mates. Others have expressed concern that behavioral studies that were based on human visual assessments of behavioral displays are no longer valid in the context of the disparity between human and avian visual perception. For example, a study of some 139 species of (human-) visually monochromatic passerines found that many were actually sexually dichromatic from the avian visual perspective. A host of research inquiries have assessed the possible role of UV perception in behavior, sex selection, foraging, chick-rearing and egg coloration with mixed results. In several recent papers researchers now suggest that the UV perception in birds should not be considered separately as a special visual channel but considered in the overall context of avian visual perception where the UVS or VS channel contributes to the overall color cognition of birds.

This was evident in a study by Ross, and colleagues, undertaken at the Lincoln Park Zoo in 2013. This study tested the preferences of birds for UV enhanced light environments. Birds were chosen to represent a variety of species and habitats. They found that birds from high light and polar environments seemed to prefer the portion of the exhibit with added UV light, spending the majority of time in that area of the habitat. Birds from more patchy light environments (i.e., forest species) spent equal amounts of time in the UV-added and UV-deficient portions of the habitat, but behaviorally seemed to be more sociable in UV-lit environments. Ultimately, while the researchers acknowledged further investigation is needed to better define optimal lighting parameters for birds, they suggested that birds living in UV positive environments are more enriched due to the visual enhancement of the environment through the addition of the UV spectrum. It was unclear from this study whether the birds' preference and social behavior in the UV-added environment was due to improved brightness or improved color perception.

Not all birds have a similar "fourth channel" because the SWS1 cone may be biased "V" or "UV". Still, the "V" bias is outside the human visual range. Therefore, light provision should include wavelengths below 400 nm. Only a small percentage of avian species have been evaluated for "UV" versus "V" bias in the SWS1 cone reinforcing the notion that science has more questions than answers with regard to UV perception and function in birds. But, pertinent to light provision, the UV preference study does reinforce what research into the avian visual system suggests: that the presence of short wavelengths (high frequency) in the light environment may improve a bird's visual function and activity within that environment. The Ross study serves as a reminder that it is both the contrast and the sum of the four types of single cones that creates both the experience of color and of brightness for birds.

Unfortunately, the standard measures of light quality used in the lighting design industry are based on the human three-channel vision system and therefore lack the ability to measure the color rendering or brightness level as perceived by birds. Further, the jargon of lighting designers and manufacturers (footcandle, lumen, color rendering, etc.) has no meaning for avian visual perception. Though these measures are still needed to assess the human-visitor visual experience, artificial light sources must be evaluated objectively for spectral composition in order to gauge how the light may be perceived by birds. Curators and designers should therefore evaluate bulbs based on the Spectral Power Distribution Curve provided by lighting manufacturers. Alternately, the spectral output of a light source can be measured using a spectroradiometer. When working with lighting designers it is recommended to ask them to evaluate environments using both measures and to combine light from a variety of bulb types to achieve the best possible spectrum. Asking the right questions and understanding the limits of the available tools, as well as impressing on lighting designers the unique challenges of avian visual perception are vital to creating the best artificial and supplemented light environments for birds.

Another consideration when evaluating the spectral quality of lighting environments for birds concerns a spectrum of UV light that is visually imperceptible to both birds and humans: ultraviolet-B (UVB, see Table 1.) UVB light is responsible for vitamin D synthesis in the skin of most species. The majority of birds receive sufficient Vitamin D from their diet or exposure to natural sunlight, so UVB as a component of lighting systems may not be needed. However, it is important to note that UVB levels in sunlight vary with time of year and latitude. UVB levels are highest at midday in summer under a clear sky but are attenuated in winter at latitudes greater than 35 degrees north or south. Nearly all artificial light sources are deficient in UVB radiation. Therefore, birds housed outdoors in winter at > 35ºN, and indoors under artificial lights, do not receive sufficient UVB levels for vitamin D synthesis. Cases of metabolic bone disease (MBD) have been reported in Humboldt penguin, marabou stork and African spoonbill chicks during winter breeding in indoor exhibits. In two of these cases, the provision of UVB light helped to improve outcomes.

In the Humboldt penguin study, chicks were hatched under parents in an indoor, artificially-lit habitat, however, the condition described was likely not due to the absence of UVB. Penguins have been housed successfully for many decades indoors under artificial light and without access to UVB. Penguin diets are typically sufficient sources of Vitamin D and there is data to suggest that penguins synthesize little,

A mixture of light environments may be important to intraspecific signaling, such as for the Andean Cock-of-the-rock. This Neotropical species chooses a lek which combines forest gaps (sun shafts) and shade; the timing of display suggests a role of UV light in their display.

if any, Vitamin D in their exposed skin under full sun conditions. The Humboldt study authors acknowledged that early poor parental care combined with an inappropriate calcium/phosphorous (Ca:P) ratio in the chick supplemental diet likely contributed to the finding of MBD and no subsequent cases of MBD have since been reported in that population. An inappropriate Ca:P ratio was also noted as contributing to MBD in marabou chicks hatched in winter holding at the Rotteredam Zoo. This 2015 study investigated vitamin supplements and UVB light exposure. Chicks receiving UVB exposure showed improved outcomes with better growth rates. This study, along with another published this year by Woodhouse and Rick, suggests that UVB exposure is important to successful outcomes for long-legged birds from open habitats. Woodhouse and Rick concluded their paper by recommending supplemental UVB light for all winter breeding African spoonbills without access to natural sunlight.

Unfortunately, there are still few UVB light sources sufficient for large exhibits; most UVB light sources must be in near proximity to birds in order to achieve sufficient power levels at the skin surface for vitamin D synthesis. Additionally, adverse reactions to UVB exposure are documented. Still, for winter breeding birds and growing chicks, UVB light supplementation has been beneficial. It may be worthwhile to evaluate adding UVB-spectrum lighting, with timer units for controlled exposure, to indoor exhibits with winter breeding birds and in propagation rooms. It is noteworthy that only relatively short exposure times are required for sufficient Vitamin D synthesis (dependent on bulb type and location). In poultry, UVB light exposure to the legs alone was sufficient to convert Vitamin D and was helpful in combination with vitamin supplements.

Despite the comparatively small amount of species-specific data concerning spectral perception and cognition in birds, we can infer from the available information that birds generally benefit from spectrally enriched environments in ways that humans cannot perceive or fully understand.

## Tick, Tock, Internal Clock

The spectral environment for birds should not be underestimated even in relation to photoperiod. Most animals use photoperiod, which is the perceived change in day length, as a calendar. Recent research suggests that not only is the duration of light essential to biological clocks, but light intensity and spectral composition may also be important.

The biological clock in birds influences all aspects of their life including sleep/wake cycles, foraging, migration and orientation, visual and immune function, reproduction and the timing of dawn song. For temperate and high-latitude birds, light is the primary cue for the entrainment or synchronization of the internal biological clock with the environment. But there may be evidence to show that even tropical birds, which can detect minor changes in day length, may use photoperiod to determine time of year. The daily (circadian) and seasonal (circannual) rhythms in birds have been well studied but the precise mechanisms of light stimulus, encoding and response are still elusive.

Birds possess the most complex time-keeping system among vertebrates. Research to date suggests that light cues that inform avian time-keeping systems appear to be mediated by two apparently separate but likely connected sensing and entrainment schemes, one circadian (following an approximate 24 hour day) and one circannual (following seasonal changes in day length), which employ both retinal (visual) and extraretinal (non-visual) light perception. Non-visual light detection is via deep brain photoreceptors (DBPs). With the exception of mammals, these extraretinal photoreceptors are present in most vertebrates and function to inform biological clocks. Current research has identified up to four separate DPBs in birds, most notably within the pineal gland and the hypothalamus. This means that light is perceived directly through the bird skull as well as via the eyes. These light cues synchronize daily activity and seasonal reproductive cycles. In general, it appears that light stimulating the pineal through the skull and the retina via the eyes control daily activity through a rhythmic melatonin release. Light stimulus to the hypothalamus appears to be most significant in the timing of seasonal reproduction. Though the research is somewhat conflicting, it may be that light perceived by the retina and in the pineal gland has little or no influence on reproductive activity. However, researchers suspect that there may be an interplay between brain centers that helps to define the overall internal calendar of birds. It should be noted that investigations of this mechanism have only been completed in chickens and a few other species, most notably Japanese quail and passerines, so the scope of photoperiodic sensing and response may yet prove to be both more complicated and species-specific. There is still much to learn about how different light spectra, intensity and duration affect avian biological clocks and outcomes.

Most bird specialists understand that light is the proximal cue for reproductive timing for temperate and high-latitude birds. But the recent research on DBPs, and photopigment spectral and intensity thresholds, suggest that there may be more to photoperiod provision than simple on/off schedules. Under natural lighting conditions there are distinct intensity and spectral changes in light throughout the day from dawn to dusk. Twilight is characterized by low intensity short wavelengths, sunrise and sunset by longer wavelengths, followed by an increase in intensity during the morning hours with additional changes in spectrum as the sun approaches its zenith. There are also intensity and spectrum differences by time of year and latitude. Pertinent to light provision, no single artificial light source provides these types of diel changes. Consequently, a variety of lamp types may be needed in combination with appropriate timing to replicate daily spectrum and intensity changes. Alternatively, indoor habitats might benefit from UV transmissible windows and/or skylights that supply daily spectrum and intensity changes at dawn and dusk with artificial light sources used as a supplement during the midday or to extend day length as required to replicate a species home latitude.

**Table 1.** Relevant approximate wavelength ranges of the EM Spectrum reaching the Earth's surface. Sunlight is filtered by the atmosphere and allows only small portions of the EM spectrum to reach the Earth's surface. UVC or extreme UV (100-280 nm) is filtered out by the atmosphere. Latitude and time of day affect the relative levels of light spectrum available.

| EM Spectrum Band | Wavelength (nm) | Description |
|---|---|---|
| Ultraviolet-B (UVB) or far UV | 280-315 | The extreme low end of this range, between 280-284 nm, is filtered out by the atmosphere and does not reach the Earth's surface; **285-315 nm is the portion of UVB involved in Vitamin D synthesis in the skin** |
| Ultraviolet-A (UVA) or Near UV | 315-400 | Within the range of avian visual perception; exact visual perception varies by species |
| Human Visible Light | 400-700 | The peak output of this portion of the EM spectrum reaching earth is within ~480-500 nm. |
| Near Infrared (NIR) | 700-1100 | Only a portion of IR radiation reaches the Earth's surface; more than 49% of the Earth's solar energy is from IR. This range is not generally visible to humans or bird species so far studied. |

Habitat elements and all light sources should be considered to have impact on the habitat light environment, including lighted graphics, substrates, reflective surfaces, etc. The indoor penguin habitat at the St. Louis Zoo's Penguin and Puffin Coast takes advantage of both direct and reflected lighting. Note the brightly lit graphics.

Bird managers share common questions regarding the best light sources for habitats and how best to manage the "dawn and dusk" light period relative to the "day". With regard to photoperiod, insight into which part of the EM spectrum is most important to photoperiodic induction can be gleaned from a 1985 study by Foster and Follett. They found that the spectrum of light entering the chicken skull was altered by scatter and absorption as it passed through tissues and blood. They identified that wavelengths from 400-450 nm and 525-550 nm were specifically reduced. However, they also determined that there is a small window where light does penetrate the brain between ~450-550 nm, with a peak transmission at 489 nm. This spectrum roughly corresponds to the avian action spectrum for photoperiodic response which is 492 nm. Shorter wavelengths do not penetrate the skull but longwave light (human-red) is the most effective wavelength at penetrating the brain tissues of birds, and may have a role in reproductive timing. The photopigment responsible for detecting light in this brain area is more sensitive to the "blue/green" light at 489 nm but because long wavelength light passes through the brain more effectively, the "red" light at 650 nm will also promote a photic response. Overall the DBPs are very sensitive to light and wavelengths at 489 nm and greater will induce photoperiodic response. This highlights again the necessity of understanding the spectral output of the chosen artificial light source and why it may be necessary to combine light bulb types in order to enrich the light environment at all points within the avian visual spectrum to correspond with photoperiodic needs. For example, at twilight, light wavelengths below 450 nm should predominate at low intensities. At sunrise/sunset periods, longer wavelengths >565 nm, but less than 650 nm, at lower intensity should predominate. The key spectrum for photoperiodic induction appears to be between ~450-550 nm with a peak at 492 nm and also is triggered at 650 nm.

It is therefore easy to understand how light bleed may be influence birds' behavioral, reproductive and molting outcomes. All light inputs and their spectral quality have effects on birds. Armed with the knowledge of the complicated interplay of physiological responses to light perceived by birds, it is not hard to appreciate that extraneous light sources in a bird's environment could confuse circadian and circannual biological cycles. Light inputs might include cleaning lights, night lighting for evening events, pathway lighting, graphics or holiday lighting, etc., which all provide light exposure to the circadian system via the retina, and at sufficient intensity, to the non-visual photopigments. Bird specialists should consider the possibility that extraneous light may be a factor influencing the successful husbandry and reproduction of a species through effects on light/dark signals. It is therefore worthwhile for managers to visit bird habitats in the evening and early morning hours to see if there are light inputs for which they are unaware. Even game cameras can be used to monitor activities around habitats during night time hours. In the habitat design phase, sighting lit graphics, pathway lights, etc., so that they face away from, and not into, habitats is recommended. Light within line of sight may affect melatonin suppression and subsequent potential for impaired immune function.

There is a wealth of data to support the impacts of light pollution on free-living birds. Light pollution is increasing worldwide, especially with the advent of LED technology. Aviary birds are likely exposed to similar pressures, especially for zoos and aquariums in urban areas. Birds in outdoor aviaries in city centers may be exposed to light pollution, such as from sky glow. Birds in indoor habitats are not immune to "light pollution" in the form of light bleed from guest and keeper areas. All light inputs have affect and should be considered as part of the total light environment experienced by the birds within their habitat.

As a correlate to this, blue light is sometimes used to replicate moonlight or as a night light for birds. It appears that moon cycles may not be important to most diurnal birds but nocturnal birds, such as some species of owls, may take light cues from moonlight. However, it is

Where feasible, daylighting options such as skylights, should be included in design as a green option as well as to take advantage of suitable spectrum. However, all materials between the light source and the subjects will affect light quality, e.g., UV transmissible, non-colored glass or plastic.

important to note that moonlight, though it appears silvery to the human eye, is predominated by long wave lengths since shortwave radiation is more easily scattered. Humans are using rod-based, achromatic vision at night, giving the moon the appearance of being white or silvery. This is another example of where human vision can mislead managers into using one spectrum over another. Blue light, depending on source and exact spectrum, should be used judiciously within a precise spectrum to avoid confusing photoperiod and the timing of biological clocks. For example, the Penguin Encounter at SeaWorld California has successfully used "white light" sourced from metal halide lamps (and more recently including a few LEDs) during the "day" photoperiod and used longer wavelength yellow and orange low intensity light for non-photoperiodic illumination for "winter" day-time lighting.

### Do you see what I see?

Light quality is not only important for the appropriate perception of color and detection of photoperiod, but also for temporal resolution. Flying requires quick assessments of, and responses to, the surrounding environment that in turn require fast neural processing of images. The speed at which images are processed is measured by the flicker fusion frequency (FFF), which is defined as the point where light pulses are perceived as a continuous stream of light. Birds tend to have a higher FFF (and a higher CFF, Critical Flicker Fusion Frequency, which is the minimum frequency at which light and images appear continuous) than humans. This area of avian vision is less well studied but several species of birds have been found to have CFFs greater than 100 Hz. In a recent investigation, the pied flycatcher was found to have a CFF of about 145 Hz.

While rapid vision in birds living under natural lighting conditions is of interest, it is most important to understand how the flicker of artificial light sources may affect birds in human care. Artificial lights will flicker at a rate of one to two times the frequency of the electrical supply (50-60 Hz or 100-120 Hz, respectively). This means that birds are likely to perceive artificial light sources as a pulse rather than a continuous light. This could have adverse effects on a flighted bird's safe navigation of an exhibit lit by light sources with a high flicker index. This means that the flicker of the light source could create dangerous "dark gaps" in visual processing affecting perceived object position.

In addition to concerns for flight, there may be welfare considerations for birds exposed to constant flicker. Humans exposed to flicker often report discomfort. Prolonged exposure can lead to headaches, dizziness, general malaise and impaired visual performance. Studies in humans suggest that visible flicker is more deleterious than invisible flicker (which is outside the perceptible range). Based on these findings it may be that birds experience similar adverse effects. But researchers that have studied flicker in chickens report mixed results. The only adverse relationship found between birds and flicker was when repetitive spatial frequency (such as caging) was combined with low frequency, high flicker light sources. In these cases, flicker was determined to have a potential negative influence on avian welfare. More research is required to determine if exposure to flicker affects vision, cognition and flight.

In the meantime, it is prudent to be aware of flicker and to reduce or eliminate high-flicker artificial light sources where feasible. In general, all lights flicker. The Illuminating Engineering Society (IES) has developed two unofficial measures of flicker: percent flicker and flicker index. In simple terms, percent flicker ranges from 0% (a light source that is steady and continuous) to 100% (a light source that produces no light at a given point in its oscillation). Flicker index incorporates information on light wave form along with percent flicker and is rated from 0 to 1. For both of these measures of flicker, the lower the number, the lower the flicker or stroboscopic appearance of the light. A more recent measure of flicker is the Stroboscopic Effect Visibility Measure (SVM).

Unfortunately, the metrics are not standardized in the industry and are rarely reported on lamp specification sheets. But some light sources tend towards higher percent flicker than others. These include, most conspicuously, fluorescent and LED lamps. In many cases, flicker can

be reduced or eliminated by using high quality, high speed ballasts (fluorescent) or high speed drivers (LED) that adjust and stabilize the electrical input. Also noteworthy, the dimming of a light source (such as with a potentiometer) will serve to increase flicker from a light source. Bird managers should work closely with lighting designers to advise them of the unique visual needs of birds to achieve the best light source(s) for the species and habitat to be lit. Ask lighting designers to provide data on the flicker metrics for lamps under consideration and measure flicker after installation. Request high speed drivers and electronic ballasts, and avoid the use of dimmers on light sources where flicker will be dramatically increased. Change fluorescent bulbs frequently (up to every six months depending on hours of use) because old bulbs flicker more than new bulbs. Inspect ballasts for proper function and replace old ballasts with updated electronic and high speed versions.

By contrast to rapid vision, birds have the ability to detect slow movements as well, much slower than the human eye can detect. Some bird species may be able to perceive the movement of constellations through the night or the transit of the sun across the sky. It has not been investigated how artificial light sources may affect this aspect of avian vision.

## Let there be light

It may now seem an understatement to say that birds have complex visual and time-keeping systems. Finding the right light source(s) to meet this diverse complexity presents a challenge. It is recommended to design habitats to take advantage of natural light where practicable. For all light sources the following parameters should be considered in the context of the intended species and from the perspective of avian visual needs:

1. Duration
    a. Latitude, photoperiod
    b. Transitions at twilight, sunrise, sunset
2. Intensity
    a. The sum of the four single cones creates the perceived brightness
    b. Latitude, time of day, time of year
    c. Use non-human-based light metrics
3. Wavelength
    a. The avian visual spectrum: ~315 – 700 nm
    b. The contrast of the four single cones creates the perceived color
    c. Extraretinal photoreception window between 450-550 nm; action spectrum for photoperiodic response peaks at ~492 nm
    d. UVB provision (250 – 315 nm)
4. Source
    a. Sunlight provides a sustained EM spectrum across the avian visual spectrum
    b. Artificial light provides variability in light spectra, often with discrete spectral spikes and devoid of UV, depending on bulb type
    c. Combining sources, via daylighting options, can improve the overall spectral characteristics of the environment while easing twilight and sunrise/sunset transitions

In all scenarios, light quality will be affected by the materials through which light passes and the reflectivity and absorption of exhibit elements. Aviary shade covers may affect light quality by filtering light spectrum into the space (e.g., green shade covers can create a green-light environment which might alter color perception and light intensity). Glass and plastics often do not transmit UV wavelengths. Dark colored exhibit elements such as substrates, rock work, walls, perching, etc. will absorb rather than reflect light. It is important to consider the full specifications and ramifications of all materials within a habitat and that are placed between light sources and birds.

The ideal light source is sunlight. Sunlight, despite its variability with weather and the seasons, provides the broadest spectrum with the best intensity. In the absence of outdoor and daylighting options, artificial lights are the only alternate sources of light for bird habitats. Given that most artificial light sources are designed for human use and tailored to human vision, the individual characteristics of light sources should be carefully evaluated. Important considerations when choosing a bulb or luminaire (which refers to the entire light fixture: bulb, housing, ballast and reflector) include

- Spectral quality (plan to combine bulb or luminaire types to improve the overall spectral quality of the environment, to add UVA, and to add UVB only if necessary)
- Ask for the Spectral Power Distribution Curve (SPD) to see a graphic representation
- Lumnaire maintenance access for cleaning and relamping (replacements of bulbs based on hours of use and resultant spectral shifts or decreases in intensity)
- Flicker metrics
- Lamp efficiency, life span, electrical requirements, cost
- Burn position of the bulb (this is the orientation of the bulb within the luminaire which can effect life of the bulb and factor in design decisions)
- Habitat dimensions (small versus large area)
- Distance from lamp to subject; the *Inverse Square Law* (light intensity is lost exponentially with distance from the source)
- Light absorption and scatter. Short wave EM radiation is scattered more easily in the environment than long wave EM radiation (that is why most UV lights specify a functional effective distance)

There are several lamp types available that are generally categorized as follows: incandescent (high- and low pressure sodium, halogen), luminescent gaseous discharge lamps (fluorescent, HID metal halide and mercury vapor, LEP) and solid state technology (LED). Each of these lamp types emits light of varying spectrum and intensity with associated variability in energy efficiency. Table 2 provides a summary of a few of the most commonly used light bulb types, their advantages, and disadvantages.

Bird specialists should evaluate the merits of specific candidate luminaires and bulbs on an individualized basis to determine suitability for a specific application. Constant advancements in lighting technology mean that the lighting technologies are ever-changing in quality and availability. But the basic approach remains the same: evaluate SPDs and combine lamps to achieve a best-fit to avian visual perception.

The visual environment for birds is only as good as the quality of light that is provided. No standards exist to measure light quality from the avian perspective or recommend lighting intensities for birds. Light meters commonly used to measure light intensity (in lux or foot candles) are based on the visual acuity of humans so are of little use for assessing the brightness as perceived by birds. However, light meters can help track relative changes in light level and be of use in tracking relative lamp function over time.

All specifications listed on cut sheets for specific lamps are also based on human visual perception. For example, White LEDs will not be perceived as white by a bird because they do not provide inputs in the UV spectrum. Bird managers should use caution in evaluating lamps and luminaires based on these parameters or light manufacturer sales pitches. Objective evaluation should be based on the scientific parameters of the specific lamp(s).

## En*light*enment

Knowledge is power and an improved understanding of avian visual systems should guide bird specialists in all stages of habitat design

**Table 2.** Summary comparison of the most often considered lighting types. (Provided as general information only; individual lamp specifications within each group may vary).

| Light Source | Advantages | Disadvantages |
|---|---|---|
| Sunlight | • Free light<br>• Energy efficient<br>• Broad spectral output<br>• Ease of twilight and sunrise/sunset transitions<br>• Intensity exceeds artificial light sources<br>• Good for large and small habitats | • Heat transfer that may impact overall energy efficiency of other habitat elements<br>• Local photoperiod, easy to augment but harder to shorten<br>• Requires UV transmissible glass, plastic or other covering for full UV transmission to indoor and aviary spaces |
| Sodium Vapor (High Pressure Sodium (HPS) | • Good for larger habitats<br>• Long life to 24,000 hours<br>• Predominance of spectrum in longer wavelengths but includes UV end<br>• Low flicker | • Predominance of spectrum in long wavelengths<br>• Moderate energy efficiency<br>• Heat production<br>• May use more energy as the bulb ages past >10,000 hours; requires relamping |
| HID Metal Halide (MH) | • Good for larger habitats, high bay applications<br>• Long life to 24,000 hours<br>• High efficiency<br>• Moderate flicker<br>• Good spectral output | • Spectral shift with hours of use; requires annual relamping<br>• Not dimmable<br>• High heat production<br>• Contain mercury; special disposal required |
| Halogen (Quartz, Tungsten) | • Small luminaire size<br>• Low cost<br>• Dimmable<br>• No warm up time<br>• Good in applications needing longer wavelengths or in combination with other shorter wavelength lights (e.g., sunrise/sunset) | • Heat production<br>• Incorrect bulb handling can affect life of bulb (use gloves to avoid transferring oils to bulb surface)<br>• Low efficiency |
| Fluorescent (T8, T5, VHO) | • Include very higher output<br>• Long life<br>• Low heat production<br>• Energy efficient<br>• Emits low levels of UV | • Flicker (can be significantly reduced with high-speed, electronic ballasts)<br>• Requires ballast<br>• Contain mercury; special disposal required<br>• Low ambient temperatures can affect function (ask for a cold weather ballast)<br>• Compact fluorescent bulbs are unsuitable<br>• Life span to~9,000 hours<br>• A 2016 study found an association between fluorescent lighting and increased risk for cataracts in *Eudypted* penguins |
| Light Emitting Diode (LED) ("White" LEDs and RGB) | • Long *rated* life<br>• Won't break like glass<br>• Color changing capability<br>• Focused light (needs diffuser) | • Focused light (needs diffuser)<br>• Failure characterized by loss of light intensity<br>• Light output reduces with age (maybe rated for 50K hours, but output may drop after 10K hours)<br>• High flicker (can be reduced by high speed driver)<br>• Distinct spectral peaks, especially RGB LEDs<br>• Sensitive to heat which will affect function and life span<br>• Circuit board (requires special disposal)<br>• Failure often requires full replacement |
| Light Emitting Plasma LEP® | • Good for larger habitats, high bay applications<br>• Directional light source<br>• Excellent SPD<br>• Dimmable to 20%<br>• Some bulbs emit both UVA and UVB spectra | • Still a developing technology (by Luxim)<br>• Contain mercury; special disposal required<br>• Emit radio frequency radiation (but are shielded to meet regulations)<br>• Strike delay (<1minute and re-strike <2 min) |

to create visually enriched environments for birds. Attention to the spectrum of light, its source and timing as well as an awareness of how all light inputs may affect birds is vital to promoting successful outcomes. Ultimately light has two forms—it is at once both particle and wave. The particles are packages of energy called photons that travel from a light source (be it from the sun or a lamp) along a specific wavelength to a destination, in this case photoreceptors, that then capture and translate them into the signals of life. Put into these terms, it may be more easily grasped that the photon (at a given wavelength) must match the capture mechanism (a given photopigment) in order to trigger a response. Understanding the duality of light in this way may help to foster a better understanding and appreciation for its impacts on the natural world and specifically on birds which have developed a complex system of photon capture and interpretation. A better understanding of the species-specific adaptations of birds is needed to further guide lighting provision. But the data available is sufficient to help drive improved avian husbandry and welfare creating enriched lives for the variety of species in need of human assistance and care.

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Absolute eye size varies across species as does the eye shape which can be globular, tubular or flat. In general owls, like this Hawaiian Owl, have large, tubular-shaped eyes which improves light collection and distance vision in low light conditions. Further research is needed to determine the exact interplay between eye structure and behavioral ecology across taxa.

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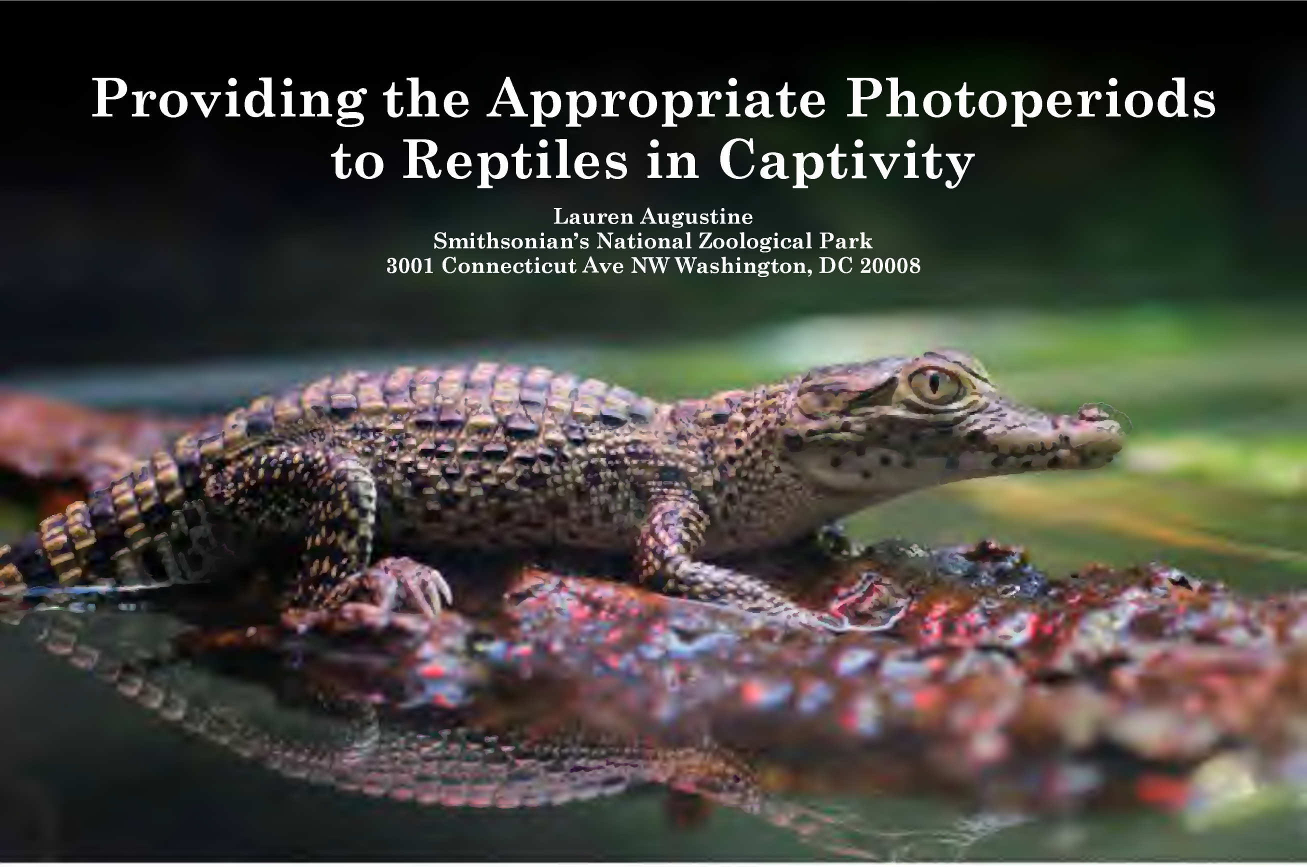
All photos by Linda Henry

# Providing the Appropriate Photoperiods to Reptiles in Captivity

**Lauren Augustine**
**Smithsonian's National Zoological Park**
**3001 Connecticut Ave NW Washington, DC 20008**



Baby Cuban Crocodile basking. *Photo by Matt Evans.*

Successful husbandry requires that the biological needs of a species in captivity are met. Because reptiles are tightly coupled to their environments, captive conditions should aim to replicate those available to a species in nature (Arena and Warwick 1995; Guillette et al., 1995; Lillywhite and Gatten 1995). The Class Reptilia is extremely diverse, therefore to keep and maintain healthy captive specimens it is important to provide taxon-specific husbandry consistent with a species' ecology and natural history (Arena and Warwick 1995; Lillywhite and Gatten 1995; Peaker 1969). In captivity, lighting elements can provide a variety of environmental parameters necessary for maintaining healthy reptiles, particularly for specimens housed indoors year-round. One such purpose is photoperiod, or the length of daylight or illumination provided each day. Light periods control various physiological and behavioral parameters and are therefore integral cyclical stimuli (Arena and Warwick, 1995) that should be considered for captive reptiles.

Depending on location, photoperiods generally change seasonally along with several other environmental factors. Although reptiles have evolved mechanisms to detect photoperiod, the circuitry through which the photoperiod is communicated to reptile tissues is not well defined (Weil and Crews, 2010). Several studies have investigated photoperiodic response in reptiles and have linked the effects of photoperiod on the reproductive cycles of several temperate species (Marion, 1982; Bartholomew, 1950; 1953; 1959; Clausen and Poris, 1937; Fox and Dessauer, 1958, Mayhew, 1961, 1964, 1965; Lillywhite and Gatten, 1995; Gavaud, 1993; Hutchinson and Kosh, 1965; Rismiller and Heldmaier, 1982). Species residing in Temperate Zones have distinct periods of reproductive activity that match seasonal changes in the environment (Marion, 1982). Often hibernation (brumation), a mechanism of energy conservation that is employed when resources are scarce (Mrosovsky, 1971), is a pertinent part of this seasonality that causes disruptions in the reproductive cycle of reptiles. The timing of brumation is influenced by both internal and external mechanisms (Licht, 1972). Photoperiod and temperature are the two most commonly recognized external factors. Rismiller and Heldmaier (1982) found that *Lacerta virdis* entered brumation based solely on a reduction in photoperiod despite a constant air temperature and availability of food.

In addition to benefiting breeding programs, photoperiod also affects the appetite and metabolism of reptiles (Lillywhite and Gatten, 1995). An increased photoperiod was positively correlated with increased appetite in *Anolis carolinensis* (Fox and Dressauer, 1957) and a reduced photoperiod induced dormancy in *Testudo hermanni* (Gilles-Baillien, 1966). Furthermore brumation can also affect a reptile's immune system and several studies have documented the influence of temperature, photoperiod and hormonal changes on seasonal variations in adaptive immunity throughout the year (Zapata et al., 1992; Munoz and De la Fuente, 2001; Origgi, 2007).

The interaction of photoperiod with other environmental factors such as temperature is an important aspect of herpetological husbandry. For example one study found that photoperiod had a significant influence on thermal tolerance on several species of reptiles, increasing their thermal maximum when photoperiod was lengthened (Hutchinson and

Kosh, 1965; Rismiller and Heldmaier, 1982). This research suggests that photoperiod may act as an environmental indicator for thermal adaptation and produce changes in the diurnal pattern of temperature selection (Rismiller and Heldmaier, 1982). Using day length as an indicator of seasonal changes is advantageous to predicting weather and food availability (Mayhew, 1964; Rismiller and Heldmaier, 1982).

Providing appropriate seasonal changes to captive reptiles is vital to keeping and breeding success. In captivity, reptiles maintained in outdoor enclosures or with sky lights are subject to photoperiodic changes naturally, although the timing of these changes may not be identical those in the animal's native habitat. Indoors, artificial lights are used to provide a variety of environmental parameters including photoperiod. Astronomical timers can be used to provide taxon-specific photoperiods automatically by setting the timer to the appropriate time zone. Photoperiods provided to captive reptiles should attempt to mimic natural cycles where possible. Managing the environmental parameters offered to captive reptiles is imperative to animal health and welfare. In addition to photoperiod, cyclical changes in humidity, temperature and diet are vital components of herpetoculture.

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Astronomical timer. *Photo by Matt Neff.*

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